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UNIVERSITY EXTENSION SERIES.

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THE VAULT OF HEAVEN

PREFACE.

In the following pages is given an elementary account of some of the marvels that have been revealed by the use of the telescope and two of its most indispensable adjuncts —the spectroscope and photographic camera. These instruments of research furnish results easily "understanded of the people," hence it has been possible to provide a fabulum which can be digested by all who are interested in astronomy.

Many of the illustrations make their first appearance here, among them being the line drawings done from my sketches, by Mr. E. B. Ridge. Mr. Cowper Ranyard kindly gave me permission to copy Figs. 35 and 36 from his excellent plates in "Knowledge," and Fig. 30 is based upon a diagram and a table of parallaxes given in the same journal. Dr. Isaac Roberts, F.R.S., has permitted me to reproduce Figs. 38, 39, and 40, from his marvellous photographs; and the Council of the Royal Astronomical Society furnished me with Figs. 21, 22, 27, and 33. Figs. 5, 11, and 13, are from Young's "Sun," by permission of the publishers; and Fig. 34 is from "The Midnight Sky," published by the Religious Tract Society. Figs. 3, 4, and 7, originally appeared in "L'Astronomie," conducted by Camille Flammarion. Two of Sir Howard Grubb's forms of telescopes are illustrated by Figs. 1 and 2; and Mr. John Browning is the maker of the instruments

shown in Figs. 9 and 10. Fig. 21 was purchased from Messrs. Cassell & Co. To all those who have assisted in the pictorial embellishment of the book, I tender my hearty thanks.

Even greater is my sense of gratitude to Mr. W. E. Plummer, M.A., who took the trouble to read the book while it was passing through the press. I am glad to have the opportunity of publicly acknowledging my indebtedness to him for many valuable suggestions.

RICHARD A. GREGORY.

WIMBLEDON, SURREY,
September, *1893*.

INTRODUCTION.

A VIEW of the sky on a fine night "when all the stars shine, and the immeasurable heavens break open to their highest," excites the wonder and stimulates the imagination of every thoughtful mind. Like brilliant gems set in the roof of a vast dome, the heavenly bodies glitter and gleam upon the dark background of space, making us conscious of the immensity of the universe in which the earth plays so insignificant a part.

The glories of the heavens have appealed to all men at all times. To primitive mankind, the earth appeared to be the centre of the universe, and all the heavenly bodies were supposed to be subservient to it. In that remote day, when science was reduced to simple deductions from the impressions, it was concluded that all things were made for man's especial benefit, the sun to serve him by day and the moon by night. The motions of the heavenly bodies were then studied because of their relation to the seasons. They regulated all mundane affairs, declaring the time for labour and the time for rest. And from the idea that these motions were created for the convenience of humanity alone, grew the pseudo-science Astrology. But clocks and calenders render it no longer necessary to note the position of the sun in order to tell the time of day, or to determine the month by observations of the stars visible in the midnight sky. The observational astronomy of the ancients, dealing with the positions and apparent motions of the heavenly bodies, has therefore left the minds of the people, and its votaries are usually confined to astronomical observatories.

The feeling of wonder at the profundity of space, and of admiration at the beauties of celestial scenery, is felt by all. In some minds the wonder is barren; in others, it gives rise to

profitable thought. An inquiring glance at the sky will show that many of the bright stars make well-marked groups, which have the same form night after night. Nearly eighteen hundred years ago, Ptolemy divided the stars into forty-eight groups or constellations, to each of which was given a name of a character in heathen mythology. The grotesque figures which appear upon star maps and celestial globes, represent Ptolemy's constellations with the addition of about twenty more created by modern astronomers. In many modern star-maps the old figures are omitted, though the distinctive names are retained. The limiting lines of the groups serve as convenient boundary marks, and are used in much the same way as the divisions which separate the earth's surface into countries. To the geographical mind, the names of countries such as France or Italy, convey a definite idea of situation on the earth's surface. In like manner, the astronomer is generally so familiar with the face of the sky, that if he observe any celestial phenomena, he is able to say whether it occurred in Orion, or Cassiopeia, or the Plough, or any other constellation. And the analogy can be carried still further. Bright stars are dotted over the sky like towns on the earth. Many of them possess proper names, such as Sirius, Vega, and Arcturus, but generally the letters of the Greek alphabet are used to designate the stars in a constellation, the brightest star being called Alpha, the next brightest Beta, and so on through the whole of the alphabet. It often happens that a star has several aliases. Thus, Sirius is Alpha of the Great Dog constellation (usually written α Canis Majoris), Vega is Alpha of the Lyra (α Lyrae), and Arcturus is α Boötis.

The stars move from east to west as if fixed to a solid revolving vault. This motion is not real, but merely an apparent motion caused by the rotation of the earth from west to east on its axis. The daily travel of the sun across the sky is explained in the same way. It is day when we are turned towards the part of space occupied by the sun, and night when we are turned away from his genial beams. The sun also appears to climb up from the western horizon towards the stars, for the

THE VAULT OF HEAVEN

AN ELEMENTARY TEXT-BOOK

OF

MODERN PHYSICAL ASTRONOMY

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stars which are high above the western horizon at sunset to-night, will, in a few weeks' time, be lost in the glows of twilight; and, shortly after, will set at the same time as the sun. In a year, however, the same stars will be found to occupy the same position. This apparent eastward motion of the sun among the stars is the result of the earth's annual revolution round him, and the path traversed is known as the "ecliptic." The stellar background upon which the sun is projected thus differs according to the position of the earth in its orbit. Stars behind the sun at mid-day to-day, will be due south at midnight in six months' time, while those now visible at midnight will form the mid-day background. In the day, sunlight illuminates the atmosphere to such an extent that the feeble star-beams are overpowered. Annihilate the sun at any moment, or strip the earth of its atmosphere, and the stars would be seen brilliantly shining on high.

Though the stars preserve practically the same relative positions upon the celestial vault from year to year, other bright star-like objects can frequently be seen which move among them. They are not stars at all, but planets or wanderers, revolving round the sun in a similar manner to the earth. There are seven large planets in addition to the earth, and nearly four hundred small ones, known to be under the controlling influence of the sun. Round the earth and five other planets revolve one or more moons, but with the exception of our own moon, none of these planetary attendants are visible to the naked eye.

The subjects treated in the following pages belong to "physical and descriptive astronomy," or "astronomical physics." Miss Clerke, in her admirable "History of Astronomy of the Nineteenth Century," thus defines this branch of celestial science: "It seeks to know what the heavenly bodies are in themselves, leaving the How? and the Wherefore? of their movements to be otherwise answered. Now, such inquiries became possible only with the invention of the telescope, so Galileo was, in point of fact, their originator. But Herschel was the first to give them a prominence, which the whole pro-

gress of science during the nineteenth century has served to confirm and render more conclusive. Inquisitions begun with the telescope have been extended and made effective in unhoped-for directions by the aid of the spectroscope and photographic camera, and (here we follow Miss Clerke) a large portion of our attention in the present volume will be occupied with the brilliant results thus achieved."

THE VAULT OF HEAVEN.

CHAPTER I.

ASTRONOMICAL TELESCOPES.

By looking through two spectacle glasses held a short distance apart, objects can be made to appear nearer. The story goes that a child's exclamation of wonder at the appearance of a church spire seen under such conditions attracted the attention of one Jean Lippershey, an optician of Middleburg, in Holland, about 1606, who afterwards fixed the lenses in tubes to form the first telescope. A patent was applied for but refused, on the quaint ground that the instrument only used one eye, whereas Nature had endowed us with two.

Galileo heard of the discovery in 1609, and made a telescope on the same principle. The instrument had lenses similar to those in a common opera-glass and only magnified thirty times. However, such optical aid enabled Galileo to discover spots on the sun, to see four moons revolving round Jupiter, to view the phases of Venus, observe mountains in the moon, and distinguish a large number of stars invisible to the naked eye. A new kind of astronomy was thus founded. Before the inventions of the telescope the positions and motions of the heavenly bodies were the

subject of study; after, it became possible to inquire what the objects are in themselves.

Though a modern astronomical telescope, with its numerous and complicated accessories, differs very considerably in appearance from the simple instrument used by Galileo, the optical principles underlying the construction of the two are much the same. Both consist essentially of a large lens, termed the "objective" or "object-glass," to form an image of the object under examination, and a small lens, or combination of lenses, to magnify the image. If the functions of these glasses are properly understood, the power of a telescope to reveal faint objects, and to magnify them, can always be estimated.

The human eye, or better, the eye of a cat, affords an excellent illustration of the use of the object-glass. In the eye is a lens, known as the crystalline lens, similar in shape to a small burning-glass. In front of this lens occurs the iris, which gives colour to the eye. A blue eye, therefore, means a blue iris, and a grey eye is the result of a grey iris. The eye-pupil is the small hole in the centre of the iris. Rays of light, which produce the sensation of sight, can only enter the eye through the pupil, and by a beautiful contrivance the size of this hole can be regulated.

Under the strong light of noon the pupil of a cat's eye appears like a very small spot in the centre of the iris. This increases in size as the light diminishes in intensity, and towards night becomes so large that very little of the iris can be seen. Now, the larger the pupil, the more rays can pass into the eye. In the middle of the day, sunlight is so intense that a very small window is sufficient to illuminate the eye-chamber, and the pupil contracts. But as the night comes on, a much larger window is required. The pupil then opens to its widest to catch as many rays as

quite beyond the reach of the unaided eye. The larger the object-glass, the larger is the bundle of rays collected by it, and the greater is the ability of the instrument to bring faint objects into view. What the astronomer wants is "more light," and it is to satisfy his cravings that giant telescopes are constructed.

So much for the function of the object-glass. Now as to the ability of the telescope to magnify the heavenly bodies. This power is obtained by means of the lens, or combination of lenses, at the eye end of a telescope. The object-glass bends the light of an object into a small image, which is then magnified by the "eye-piece." Every boy knows that a burning glass will concentrate the sun's light to a brilliant point. The distance of this point from the lens is known as the "focal length" of the lens. Now, the magnifying power of any telescope is calculated by dividing the focal length of the object-glass by the focal length of the eye-piece. But the focal length of the object-glass of any one telescope is always the same, hence the stronger the magnifying glass, that is to say, the less the focal length of the eye-piece employed with any telescope, the greater is the magnification produced. The magnifying power can thus be varied at will by inserting different eye-pieces in the telescope. Usually several eye-pieces are supplied with a telescope; and a large instrument has a stock capable of magnifying from fifty to about one thousand times.

Let us consider exactly what this means. A man at a distance of a thousand yards appears to have a certain height. If a telescope, with a magnifying power of two, is used to view the individual, he will appear as if seen at half the distance; a magnifying power of three will enable us to see him as if he were situated at one-third the distance, and so on for other magnifications. When the man is seen at

half his original distance, his apparent height is doubled. In the same way magnifications of one, two, three, or four hundred brings the selected object one, two, three, or four hundred times nearer, and the size of the object is increased according to the proportion which the diminished distance bears to the real distance. This principle applies to celestial as well as terrestrial objects. The moon is at a distance of 240,000 miles from the earth. If this distance could be halved, the apparent diameter of the moon would be doubled. We cannot, of course, increase or decrease the real distance of the moon, but by magnifying our satellite we can bring about the same result as far as appearances go. An instrument of moderate dimensions will show the moon as she would be seen at a distance of five hundred miles, and any lunar streak or mark a quarter of a mile long can then be easily distinguished.

During the opposition of Mars in 1892, the planet passed the earth at a distance of about thirty-five million miles. If it had been possible to use a power magnifying one thousand times, when observing our ruddy brother, he would have appeared one thousand times nearer to us, that is, at a distance of thirty-five thousand miles. But it was not possible to obtain such a high magnification, for there is a limit beyond which magnification cannot be carried with advantage. And for this reason: we see things through an atmospheric veil, "which whirleth about continually." When objects such as the sun, moon, or planets, are magnified telescopically, the tremors of our aerial envelope are magnified in the same proportion. Hence a limit is eventually reached, when atmospheric imperfections become so troublesome that further improvement of seeing is rendered impossible. For many observations in astronomy, however, a high magnifying power is undesirable and in some cases useless. This

comes as a shock to the ideas of the majority of visitors to observatories. They expect to see stars at least as big as saucers, and can hardly realise that it is impossible to magnify these distant orbs. In a good telescope, a star appears simply as a point of light more or less brilliant according to the size of the object-glass, but possessing no particular features. Indeed, the existence of a pretty colour round the image of a star is an indication that the telescope is not so perfect as it ought to be. But though stars cannot be magnified, the space between them can. Hence it is that many stars which appear single when viewed in a small telescope are found to be composed of two when seen with a high magnifying power on a large telescope.

At the present time, the largest telescope in which a glass lens is used to condense the beams of light is at the Lick Observatory, Mount Hamilton, California. The object-glass is a yard in diameter, and the length of the telescope tube is sixty feet. This instrument will show 100 million stars, that is, a star each for every English-speaking individual on our globe. The second largest refracting telescope has a lens thirty inches in diameter. It is erected at Pulkova in Russia. There are seven other instruments more than twenty inches in diameter now in existence. England possesses two of these: one is at Greenwich Observatory, and the other was presented to the University of Cambridge by Mr. Newall in 1891. After considerable difficulty a firm of optical glass manufacturers has managed to cast a disc of clear glass and work it down to a lens forty inches in diameter. The instrument for which this massive lens is intended will probably be erected near Chicago.

Besides the familiar kind of telescope, known as "refractors," there is a class known as "reflectors," in which a concave mirror, shaped like the mirror sometimes placed

behind a gas light, takes the place of the large lens. We have seen that a convex lens is able to produce a real image of an object. A concave mirror also possesses the property of forming an image capable of being caught upon a screen, and, therefore, designated "real." The difference between the two results is that in one case the light passes through the lens and forms an image on the opposite side, in the other it is reflected to form an image on the same side as the object. But in either case, an eye-piece is used to magnify the image. There are several ways in which the mirror is arranged with respect to the eye-piece. One method is to fix a flat disc of silvered glass at the upper end of the telescope tube, but inclined at an angle of 45°. The concave mirror is at the bottom of the tube. Rays of light pass down the tube to the mirror, and are concentrated to an image which is reflected to the inclined flat disc, and thence to the eye piece at the side of the tube. Hence the observer, instead of looking straight at an object, sees it sideways. The flat disc stops a few of the rays of light from passing down to the concave mirror. What is more, light is lost by reflection from the disc as well as from the mirror. In order to obviate this double loss in the Newtonian reflector, Sir William Herschel arranged his concave mirror slantingly in the bottom of the telescope. The image is then directly reflected to a point near the top of the tube. In this case, the observer stands with his back to the object he is viewing.

It can readily be understood that it is less difficult to make a large mirror than to cast a disc of glass without blemish. On this account the largest telescopes in the world are reflectors. The renowned instrument erected for Lord Rosse at Parsonstown, Ireland, is of the same length as the Lick telescope (sixty feet), and has a diameter of six

feet, so that the tube can be walked through without the necessity of stooping. The next in size is a magnificent instrument (five feet in diameter), constructed and possessed by

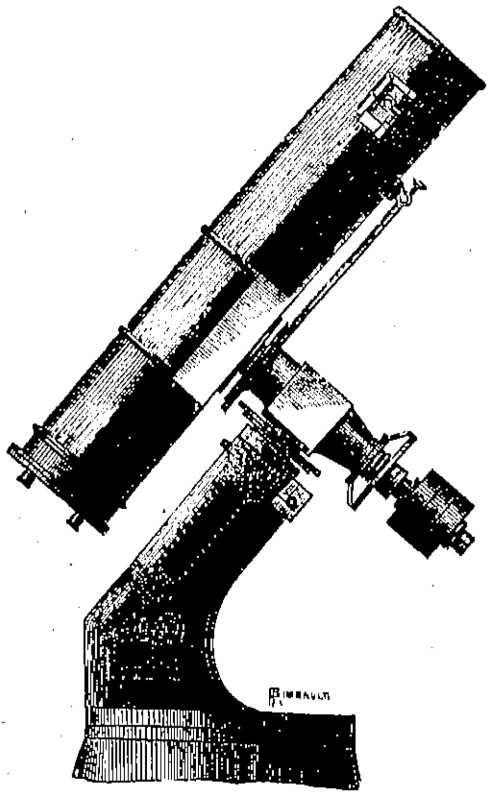


Fig. 1.—A Newtonian reflecting telescope, equatorially mounted.

Dr. A. A. Common, of Ealing. Several four-feet reflectors have been made, though only one, at Melbourne, is now used. A reflector ten feet in diameter and a hundred and

forty feet long, is being constructed for the Paris exhibition of 1900. With the clearest sky and the highest magnifying power on this instrument, it is estimated that the moon will be brought within a distance of fifteen miles from the earth.

A large telescope is of very little use unless it is mounted so that it can readily be pointed towards any part of the sky. More than this, on account of the apparent motion of the celestial sphere, if a telescope is sighted at a star, a few minutes afterwards the star has been carried towards the west, and the instrument is left pointing to another object. If we wish to observe the star continuously, the telescope must be moved at the same rate as the apparent motion of the sky. These desiderata have to be realised in all telescopes designed for the study of the aspects of celestial objects. An astronomer first points his telescope to he object he wishes to observe, and then connects it with a clock-work arrangement, which will drive it at the same rate as the stars. Should the sky afterwards cloud over,

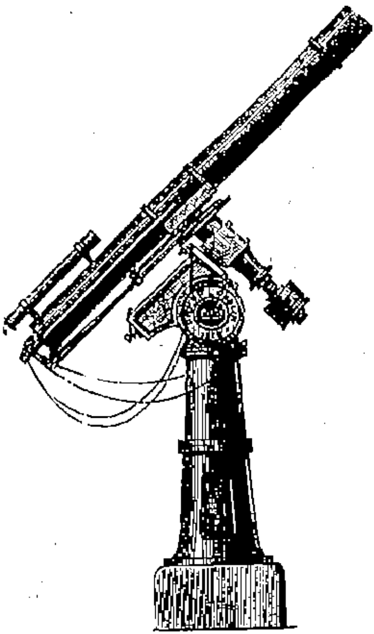


Fig. 2.—A small equatorial telescope.

the telescope can be left to itself for a time, but when I sky is clear again the astronomer goes back, and is able continue his work without any re-adjustments, for the strument will still point to the object to which it had b directed. But for this ability to follow the stars, celes photography would be impossible. When a photograp is taking a portrait, he generally prefaces the taking the off the lens with the admonition to "Keep still, please." the advice of the photographer is not followed, a blur picture is the result, for the features of the sitter act different parts of the photographic plate. But the heave bodies do not obey the will of the astronomer in tl movements, and to get over the difficulty the telescope to be mounted and driven so that it follows them ac the sky.

In addition to the instruments used for observing physical characteristics of celestial bodies, there is a c the function of which is to accurately determine positi The former is for celestial sight-seeing, the latter furnis the facts for mathematical investigations. This kind instrument is not mounted so that it can be directed any part of the sky. Crossing the middle of the tube is axis, which rests on two firm supports, and points exa due east and west. The tube itself thus always lies i true north and south direction. It can be moved up down, but neither to one side nor the other. Upon lo ing through a "meridian instrument" of this kind, sev very fine upright lines will be seen, with one or two otl crossing them horizontally. These lines—usually mad spider thread—serve a most important purpose. The strument is fixed. In stately and grand procession stars appear at one side, cross the upright lines one a the other, and then disappear on the opposite side.

desire to know the precise moment at which a selected object is in the centre of the field of view of the telescope. The observer seats himself at the instrument with his finger on a small knob. When the object passes behind each line he sharply presses down the knob, and in so doing sends an instantaneous current of electricity through a wire with which it is connected. The current causes a little pricker to make a mark on a revolving drum. A clock is connected electrically with the same pricker, and causes it to make a mark on the drum every second. In one second the drum turns through two or three inches, so the two pricks made by the clock-beats are separated by this current. Between these pricks occur the extra marks produced by the observer's signals, and by measuring the distances of such marks from them, the exact fraction of a second at which the object crossed the line can be estimated. The "transit," or passage of the object across each upright line is signalled and recorded on the revolving drum, and from the marks the exact time at which the object crossed the central line is found.

If the exact time at which a star crosses the central line is noted two nights in succession, the interval will be found to be 23 h., 56 m., 4 s. of mean time. Whatever star is selected and whenever the observation is made, the interval is always the same; it is the time taken by the earth to rotate on her axis, and is known as a sidereal or star-day. The astronomer deals so much with the stars that he would almost be expected to use the star-day instead of the day of civil life. And, for convenience, he does so. The astronomical clock has the same appearance as a well-constructed clock keeping ordinary time, indeed, if it were required, it could be regulated to keep proper time. Astronomers want the clock to keep star-time, so it is regulated until the hour

hand goes through the twenty-four hours marked on the face in the interval between two successive passages of a star across the central line of the meridian instrument. When this is the case, the hour hand makes a complete revolution in 23 hours, 56 minutes, 4 seconds, of ordinary time. An astronomical clock, therefore, gains about four minutes a day upon the time in general use.

Now, it is so arranged that the clock of the astronomers always indicates 0 hours, 0 minutes, 0 seconds, when a particular point in the sky is due south, that is, on the meridian. The point selected is that upon which the centre of the sun is projected at the time of the spring equinox, and its position in the sky is very accurately known. Once a day it passes across the field of view, and when it does so, the clock begins its round of twenty-four star-hours. Suppose the star-time to be 3 hours, 6 minutes, 18 seconds, when a certain star is observed to transit, then whenever the sidereal clock indicated that time at the place, whether by day or night, the star would be in the same position, presuming, of course, that the clock was an absolutely accurate time-keeper. In other words, the sidereal time indicated when any star transits a particular meridian is always the same for the same star. This furnishes a means of determining the positions of stars round the sky in an east and west direction. The number of sidereal hours, minutes, and seconds which elapses between the passage of the starting-point and the passage of a star across the centre of a meridian instrument is observed, and termed the star's "Right Ascension." Evidently, many stars have the same right ascension, that is, they are due south at the same time, though at different heights above the horizon. Hence, to exactly locate a star, we must not only know the distance in an east and west direction from a "prime

meridian," but also north and south of a fixed datum line. Suppose we could see twenty-four lines, each stretching from the north to the south celestial pole, like the lines of longitude upon a map or globe of the earth; the interval between two lines would then represent an hour of right ascension. Now, the celestial poles are the points in the sky around which the stars appear to revolve, and the celestial equator is mid-way between them. If the two legs of a pair of compasses are opened until they are perpendicular to one another, and one of them is pointed towards a celestial pole, the other then points to the celestial equator. The smallest angle between the legs when one points to the equator and the other to a star, in other words, the angular distance of a star from the celestial equator, goes by the name of "Declination." It corresponds to terrestrial latitude. Every one knows that the position of a place upon the earth is defined when its latitude and longitude have been obtained. In a similar manner every star in the sky has a particular Declination and Right Ascension, and when these two co-ordinates are known the star can be found.

By means of circles attached to the axle supporting a meridian instrument the declinations of celestial objects are determined with extreme accuracy. These circles are made large in order that a very small angle may be represented by a comparatively long distance on the circumference. An instrument of this character approaches perfection as near as it is possible to do. The circles are divided by delicate machinery in so accurate a manner that a microscope will not reveal any difference of length between the lines, and the axle to which the tube is fixed is turned so as to be absolutely the same distance across at every point. Indeed, in many respects the instrument is so perfect that

the earth is not a fit place for it. The "foundations of the earth" are very shaky, and the instrument is troubled by continual earth-tremors and changes of level. Further, the atmosphere bends the light of celestial objects so as to make them appear higher than they really are. If the effect were

Fig. 3.—The meridian instrument in the transit room of the U. S. Observatory, Ukiah, California.

constantly the same it could be allowed for, but it is greatest near the horizon, and diminishes to the zenith, where it is nothing, and it varies according to the state of the air, and the time of year, intervening always between the hope and

the realisation of perfection. But even if the earth could be annihilated and the astronomer were left with his instrument of precision to perform the revolution round the sun, he would find that it possessed inherent defects. The tube bends very slightly, and varies in length, the circles are not graduated with mathematical accuracy, and the axle is not perfectly cylindrical in shape. More than this, the astronomer himself is not to be relied upon. When an observer sees a star cross a line in his meridian instrument, a certain interval of time elapses before his mind causes his hand to press down the electrically-connected knob. This interval is different for different individuals, and diminishes as an observer becomes used to his work. In spite of all these things, however, the meridian instrument is a mighty power in the hands of astronomers. With it all delicate celestial measurements are made, so that it forms the fundamental instrument of every observatory of any pretensions.

A large telescope not only needs to be mounted conveniently, but also requires proper housing. The observatory is usually a round house, surmounted by a cupola or dome, resting on rollers or wheels, and therefore capable of being revolved. On one side of the dome, extending from the top to the bottom, is a slit about a yard wide, which can be opened or shut at will. When an astronomer wishes to begin work, the shutters of the dome are opened, and he points his telescope in the proper direction. As the night goes on, and the stars shift their apparent positions, the dome is moved round to enable the telescope still to point to the object under examination, and the astronomer moves his observing chair so as to be able to continue his scrutiny. In an observatory designed to minimise inconveniences, the observing chair is slung from the dome, and the dome itself is driven round by the clock which drives the telescope, so

that all it is necessary to do is to open the shutters, point the telescope, take a seat in the observing chair, and observe as long as desirable. For meridian instruments a dome is not required. The house can be any shape, provided there is a slit open to the sky in front of the telescope. The observer

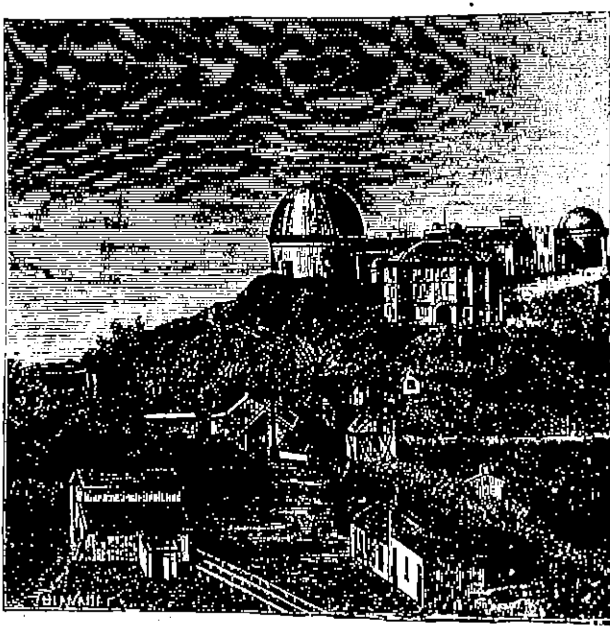


Fig. 4.—The Lick Observatory, California, having at present the largest telescope in the world.

then seats himself as comfortably as possible at the eye end and observes the stars as they pass across the field. His mind is strained to the utmost as he records the transits one by one, and a quarter of an hour or so of such work is sufficient to tire the most enthusiastic observer.

The modern astronomical telescope has a number of accessories, but want of space will not permit us to describe them here. Our knowledge has been extended in unhoped-for directions by means of the photographic camera and the spectroscope, and some of the results obtained with these potent engines of research will be described in a later chapter.

CHAPTER II.

THE LIGHT OF THE WORLD.

"O, 'TIS the sun that maketh all things shine!" that guides the planets in their course, that is the giver of all good, the source of all energy. This orb of heaven is so majestic in his motions, so mighty in power, that it seems almost like sacrilege to apply to him the yard-stick, to weigh him, to scan his features through optic-glasses, and overhaul him in much the same way that a criminal is investigated for purposes of identification. However, these poetical scruples must be put aside, for astronomers have subjected the god of light to a ruthless examination in order to reveal the mystery of his being.

The distance of the sun from the earth is about 93 millions of miles. There is a difficulty in properly grasping the significance of this immense number. Suppose we could stretch a row of bodies of the same size as the earth across the abyss, which separates us from our luminary, the number required to complete the line would be 11,600. Nowadays, people are fond of globe-trotting, of making a journey round this world of ours. Roughly speaking, "the grand tour" involves a journey of about 24,000 miles, and is done in about sixty days. Now, a traveller fired with the ambition of travelling as many miles as separate us from the sun would have to make nearly four thousand journeys before he had attained his desire, and if he had been started on his

circuits as soon as he was born, he would require to live about six hundred years to finish his task. Let us take another illustration. A sensation travels through the nerves at the rate of about a hundred feet in a second. Suppose a child were born with an arm long enough to reach to the sun so as to burn his finger, the sensation would start on its journey, but the child would have to live 160 years before it had reached his brain and made him realise the pain. Sounds travel through the air at the rate of about 1,100 feet per second. If it could be transmitted through space with the same velocity, an explosion on the sun would be heard on the earth rather more than fourteen years after it had occurred. Light is a much swifter messenger. It travels at the enormous rate of 186,000 miles in a second, so that the light we receive from the sun at any instant left him eight minutes previously.

The sun is three million miles nearer the earth in winter than in summer. The difference between the greatest and least distances is found by measuring the change in the sun's apparent size. The annual variation amounts to one-thirtieth of the whole solar diameter. Now, there is a very definite relation between apparent size and distance. A stick a yard long seen at a distance of fifty yards appears of the same size as one two yards in length at twice the distance, or three times the length at three times the distance. In fact, if two objects at different distances appear of the same size, the real sizes are exactly in proportion to the distances. Let us apply this principle to find the size of the sun. A halfpenny placed at a distance of nine feet from the eye just covers up the sun's disc. The diameter of the coin is an inch. Hence an inch at nine feet appears of the same size as the sun, which is 93 million miles away. The sun has therefore a diameter as much

longer than that of the halfpenny as 93 million miles exceeds nine feet. By working out this proportion the diameter is found to be about 860,000 miles. Accurate measurements show that the value is 866,000 miles. Comparing this with our little world, we find that it would take 109 earths in a row to stretch from one side of the sun to the other, and 342 would be required to make him a girdle. His volume is more than one and a quarter millions greater than that of the earth. If we had a contract to build up this stupendous bulk, and were to deliver a load of the same size as the earth every hour, the order could be completed by working day and night for 150 years.

Though the sun is one million three hundred thousand times bigger in bulk than the earth, he is only 330,000 times heavier. This shows that the density of the sun is about one quarter that of the earth. The earth, as a whole, is rather more than five and a half times heavier than a globe of water of the same size; the sun, as a whole, is less than one and a half times heavier than it would be if composed of water. But we hasten to remark that, both in the case of the sun and the earth, the density increases from the surface down to the centre. The upper parts are lighter, bulk for bulk, than the lower, and the numbers given represent the average density.

The weight of a body on the earth is simply the pull of the earth upon it. At the sun's surface the pull is nearly twenty-eight times greater than at the surface of our globe. It results from this, that anything transported to the sun would appear to have its weight increased nearly twenty-eight times.

To the naked eye the sun appears like a flat disc, but when observed with even a small telescope many interesting objects can be seen. In making such observations,

however, some method of screening the eye from the fierce beams of the sun must be used. A tinted glass is usually put over the eye end of the telescope, and in a small instrument this tones down the light and heat sufficiently to permit the solar surface to be observed. For large instruments, special devices are employed to diminish the power of the rays before they reach the eye-piece and dark glass; if this is not done, the great heat may melt the tinted glass, besides injuring the eye of the observer. Another method of viewing the sun's surface is to fix or hold a sheet of white cardboard at a short distance from the eye-piece. The sun's image will then be projected upon the card, and any spots or markings upon the surface are conveniently seen.

One of the first things that strikes a solar observer is that the visible surface of the sun—the "photosphere," to give it a name—is darker near the edges than at the centre. A close investigation of the photosphere shows that it has a texture, a mottled appearance, very similar to that of mottled cardboard. The marks go by the name of "nodules" or "rice-grains," and though they are "minute" objects on the sun, the smallest are as large as Great Britain. In places, the rice-grains are seen to be lengthened so as to have the form of "willow leaves." When the rice-grains are observed under perfect conditions, with a good instrument, and by an acute observer, they are seen to be themselves made up of smaller luminous points known as "granules." Prof. S. P. Langley has examined the minute structure of the solar photosphere and depicted it with marvellous accuracy. The following remarks of his are therefore of great interest. Describing the appearance presented by the solar surface in telescopes of moderate size, he says: "We see a disc of nearly uniform brightness, which is yet sensibly darker near

the circumference than at the centre. Usually seen relieved against this grey and near the edges, are elongated and irregular white patches, *faculæ*, and at certain epochs trains of spots are scattered across the disc in two principal zones equidistant from the solar equator. On attentive examination it is further seen that the surface of the sun everywhere —even near the centre and where commonly neither faculæ nor spots are visible—is not absolutely uniform, but is made up of fleecy clouds, whose outlines are all but indistinguishable./ The appearance of snow-flakes which have fallen sparsely upon a white cloth partly renders the impression, but no strictly adequate comparison can perhaps be found, as under most painstaking scrutiny we discern numerous faint dots on the white ground, which seem to aid in producing the impression of a moss-like structure in the clouds still more delicate, and whose faint intricate outlines tease the eye, which can neither definitely follow them nor analyse the source of its impression of their existence.

"Under high powers used in favourable moments, the surface of any one of the fleecy patches is resolved into a congeries of small, intensely bright bodies, irregularly distributed, which seem to be suspended in a comparatively dark medium, and whose definiteness of size and outline, although not absolute, is yet striking by contrast with the vagueness of the cloud-forms seen before, and which we now perceive to be due to their aggregation. The 'dots' seen before are considerable openings caused by the absence of the white nodules at certain points, and the consequent exposure of the grey medium which forms the general background. These openings have been called *pores*." Prof. Langley then goes on to say that, in moments of good vision, the nodules or rice-grains were seen to be formed by aggregations of minute points of light,

to which he gave the name of "granules," and after a careful study, it was concluded that "The ultimate visible constituents of the solar photosphere being not the rice-grains, but smaller bodies which compose them, and the size of these latter being valuable at not over 0$''$.3 [135 miles], from a comparison of the total area covered by them with that of the whole sun; we are entitled to say that the greater part of the solar light comes from an area of not over one-fifth of its visible surface."

To the untrained observer a small sun-spot looks like an accidental speck of dust upon the eye-piece of the telescope. An examination, however, soon shows that a sun spot has an appearance of its own. It is not uniformly dark, but is made up of two shades, known as "umbra" and "penumbra." The umbra is a dark portion, more or less in the centre, and the penumbra is a lighter part surrounding it like a fringe.

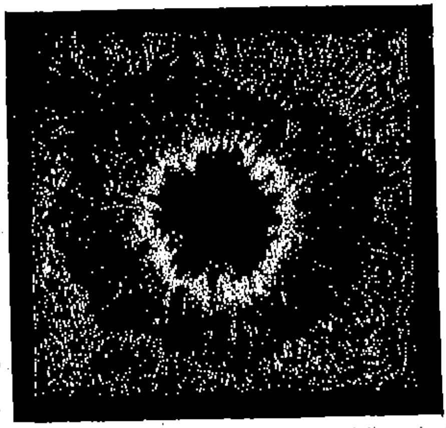


Fig. 5.—A sun-spot is not uniformly dark, but is made up of two shades, known as umbra and penumbra.

In the majority of cases, sun-spots are very irregular in form. Groups of spots are frequently seen; they sometimes present an appearance such as that produced when a boy throws a handful of mud upon a whitewashed wall. As a rule, one of the spots of a group becomes larger and more

circular in shape as the group grows old, while the smaller ones disappear.

Sun-spots are not only interesting objects to observe, they furnish astronomers with a very important fact concerning the sun. If the positions of spots on the sun's face are noted day after day, they will be found to vary. A spot just on the eastern edge of the sun yesterday, appears more on the face to-day, and to-morrow it will be seen to have moved still farther towards the centre of the disc. In about a fortnight after the first observation, the spot disappears round the sun's western edge. The explanation of this motion of spots from east to west is that the sun is in rotation. The spots are on the sun's surface, and are carried round on account of his spinning motion. Since this is the case, it is evident that the time taken by the sun to make a complete rotation can be found by determining the time occupied by a spot in moving once round. The average time is 27¼ days. Owing to the fact that the earth is a moving observatory, this is not the true length of the sun's period of rotation. We see a spot half-way across the sun's disc, and if we were fixed in space, the spot would regain its position after 25⅓ days. But our "mother earth" cannot waste her time to let us study sun-spots under the simplest conditions. She bears us away, while continuing her monotonous journey, and in 25⅓ days has travelled through one-fourteenth of her yearly track. The result is that after this interval, the spot is seen to the east of the sun's centre. It has to catch up to the earth, and takes nearly two days to do so and to appear once more half-way across the visible disc.

A peculiar fact with regard to the rotation of the sun is that spots near the solar equator show a quicker rate than spots observed in higher latitudes, quicker, indeed, by as much as two days.

The rate of rotation, as deduced from observations of spots, decreases from the solar equator. This fact has a very important consequence. It shows that the sun cannot be a solid globe, for then the rotation period would be the same in all parts. Unfortunately, there is no opportunity of studying the rate of spot movement near the poles. On very rare occasions, small spots are seen midway between the equator and poles, but none appear in higher latitudes than this. In the vast majority of cases, spots are only seen between the limits of two bands or "zones," extending from five degrees to forty degrees in the north and south solar hemispheres. Spots seen beyond these limits are regarded as out of bounds. The parts of the sun's surface thus favoured by spots are known as the "sun-spot zones."

The sun, then, is in rotation. If he rotated with his equator lying in the plane of the ecliptic, the spots would be seen to move straight across from east to west at all times of the year. But they do not. In March the paths are curved, and spots reach their *highest* point when half-way between the east and west edges. Six months later, spots curve down from the east edge and then climb up to the

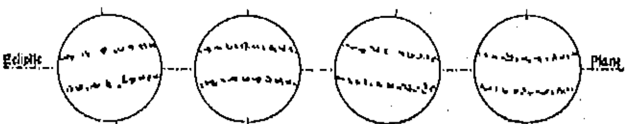


Fig. 6.—"In consequence of the inclination of the sun's equator to the ecliptic plane, the spots appear to traverse different paths during different times of the year."

west, reaching their *lowest* point when half-way between the two edges. From this it is inferred that the sun does not rotate with his equator in the plane of the ecliptic, and its

axis perpendicular to it. The axis of rotation has a fixed direction, but it crosses the ecliptic plane slantingly. In March, the earth is on the side of the sun towards which his south pole is leaning; in September we are on the opposite side of our orbit, and the north pole of the sun looks towards us. For these reasons we get up-curves in March and down-curves in September. In June and December, we see the sun, as it were, sideways. Both the north and the south pole are then at the same distance from us, and the spots are therefore seen to travel straight across the disc.

Sun-spots appear dark on account of the dazzling brightness of the background upon which they exist. As a matter of fact, if a spot could be isolated from the sun, the darkest part would be found to have a brilliancy greater than that of the lime-light used in lantern illustrations. Not only are sun-spots darker than the surrounding surface, they are certainly cooler. What is more, they are hollows or cavities. This is proved beyond doubt by watching the appearances of spots differently situated on the sun's disc. It is easy to understand that a depression on the surface of the sun must be seen under different aspects as it is carried from the eastern to the western edge. And observations show that when a spot is seen centrally, when we peer straight down the cavity, the penumbra usually surrounds the umbra in a fringe of more or less regular width. As a spot moves towards the western edge, it becomes more and more foreshortened in appearance. At the same time, the fringe of penumbra is widened on the outer side, and diminishes in width on the inner side. In a few cases spots have been seen as very slight notches on the edge of the sun, and have even been photographed in this position. A good imitation of a normal sun-spot and its varying aspects is obtained by painting the centre of a saucer

black and the remainder grey, and then viewing it under different aspects. When we look straight at th saucer, the grey part is seen to surround the black part uniformly, and as we view it, more and more askew, a foreshortening precisely similar to that observed in the case of sun-spots is seen.

As to the size of spots. The greatest length of the generality is something between 500 and 40,000 miles. Occasionally giant spots are on view. One of the largest was visible on the sun in February, 1892. Its length at one time was 92,000 miles, and breadth 62,000 miles. A number of small spots hung round the large one, and the entire group had a length and breadth of 162,000 and 75,000 miles respectively. The area of the large spot was 2,900 millions of square miles, and when all the group was measured, they were found to have a surface of 3,500 million square miles, that is to say, seventy bodies of the same size as the earth would be required to cover up the immense gap.

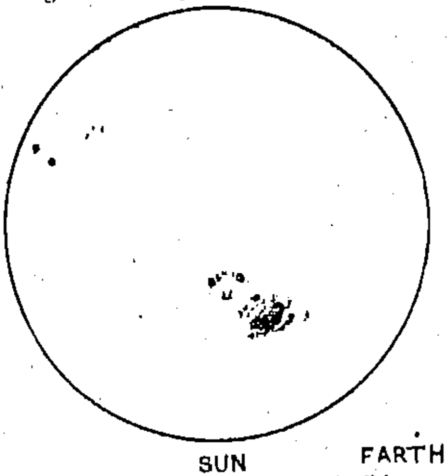


Fig. 7.—Spots seen upon the sun in February, 1892. The small dot outside the circle represents the proportional size of the earth.

It will have been concluded from what has been already said, that sun-spots are not permanent blotches on the sun. They are born, live a life of usefulness to astronomers, and

die. The average life is a month or so. Some die when a few days old; others go off suddenly in their prime, but the majority grow to maturity, and then decay, like ordinary mortals. In one or two cases, spots have lived more than twelve months, but it is rarely that such a green old age is reached.

A number of bright fragments or shreds known as "faculæ" can usually be seen near sun-spots, and become conspicuous in the neighbourhood of spots not far from the sun's edge. Faculæ are elevated portions of the sun's visible surface. A direct proof of this lies in the fact that they have been seen as slight projections on the edge of the sun. But it must not be supposed for a moment that faculæ are permanent mountains on the sun. "They flow from form to form" in a few hours or days, and are frequently so evanescent that it is almost impossible to sketch them. Faculæ have not an established promenade across the sun like spots. Excepting the polar regions, they are distributed pretty uniformly all over the surface. This is considered a fortunate circumstance, for by observations of faculæ it becomes possible to find the rate of the sun's rotation in regions beyond the spot zones.

Schwabe, a native of Dessau, commenced his observations of the sun in 1826, with the idea that the labour "might be rewarded by the discovery of a planet interior to Mercury." He was then led to inquire into the rotation of the sun as indicated by the spots. Each spot was noted and numbered in the order of its appearance, and when this system of registration had been carried on to the end of 1843, Schwabe modestly remarked that the number of spots visible upon the sun varied periodically, waxing and waning in what seemed to him to be a period of about ten years. But the subject attracted little attention, and it was not

until 1851 that astronomers began to wake up to its importance. In 1857 the gold medal of the Royal Astronomical Society was presented to the indefatigable observer of Dessau. "Twelve years," remarked the President of the Society in his address, "he spent to satisfy himself, six more years to satisfy, and still thirteen more to convince mankind. For thirty years never has the sun exhibited his disc above the horizon of Dessau without being confronted by Schwabe's imperturbable telescope, and that appears to have happened on an average about 300 days a year. So, supposing that he observed but once a day, he has made 9,000 observations, in the course of which he discovered about 4,700 groups. This is, I believe, an instance of devoted persistence (if the word were not equivocal, I should say pertinacity) unsurpassed in the annals of astronomy. The energy of one man has revealed a phenomenon that has eluded even the suspicion of astronomers for 200 years! Let us hope that the example will not be lost. Men are apt to speak of astronomy as an exhausted science, meaning that all that can be known is known. No doubt being the most perfect, it is in one sense the most exhausted science. But the astronomer of Dessau has taught us that there are still mines rich in ore, though they lie deep buried, and must be worked with more assiduity and with more care. I can conceive few more unpromising subjects from which to extract a definite result than were the solar spots when Schwabe first attacked them."

Since the delivery of this address thirty-six years have passed, and the evidence obtained during this period has been used to elaborate Schwabe's discovery. The average period or interval in which spots ebb and flow, so to speak, is found to be rather more than eleven years and a month. An important fact is that the decrease always takes longer

than the increase of spottedness. In the middle of 1889, six weeks passed without a single spot being seen upon the sun. This represents a "minimum" of solar activity, for the spots afterwards began to appear. The numbers have since been increasing, and about the end of this year (1893), that is four and a half years after the minimum, the activity of the sun, as evidenced by the spots, will be at a maximum. Instead of increasing in numbers, a decrease will then occur, and in 1900 the state of the sun in 1889 will be again reached. The rise to maximum takes about four and a half years, and the fall to minimum a little more than six and a half years.

Numerous more or less successful attempts have been made to establish a relation between terrestrial phenomena and solar spottedness. On the face of it, it would appear that the temperature of the earth must vary according to the number of spots on the sun, for it has been proved directly that spots are cooler than the surrounding photosphere. This being so, when a large spot is on the sun, the total amount of light and heat received must be different. It has been estimated that when the spot of February, 1892, was largest, the sun was experiencing a loss of light equivalent to that given by 2,200 full moons. In spite of this, terrestrial weather did not appear to be influenced. Indeed, when the matter is well examined, no direct effect would be expected. The loss of light due to the presence of the spot was less than one-twentieth of the variation due to the fact that the earth is three million miles nearer the sun in winter than in summer, and even this change is too small to be noticeable. Logically, of course, some difference must be produced by spots, though the effect may be, and is generally, obscured by vicissitudes of the weather due to local circumstances. Leaving individual spots out of the question, several investi-

gators have shown that the meteorology of our planet fluctuates with the periodic variation of solar activity. The temperatures of a few regions not subject to irregular variations have been proved to be slightly below the average when the sun is most spotted, and above the average when he is least spotted. Upon first considerations, this is the kind of result one would expect, the argument being that the greater the number of spots, the less must be the amount of light and heat emitted by the sun. But it must be remembered that an increase in the frequency and extent of spots means an increase of solar activity. Indeed, there is little doubt that the sun is hotter, as a whole, during a maximum than during a minimum period of the solar cycle of changes, and the reverse indication obtained from a discussion of the heat received by the earth must therefore be added to the long category of unexplained facts.

Cyclones in the Indian Ocean seem to be most frequent when sun-spots are most frequent. The rainfall of Ceylon, Southern India, and Australia, has also been shown to be most abundant about the time of maximum, and least near minimum epochs. Both these phenomena indicate that the sun is hottest when most spotted. No sufficient cause has been found to reconcile the temperature observations with those of cyclones and rainfall. The discrepancy will probably be accounted for when there are more facts to work upon.

The connection between solar activity and terrestrial magnetism is much more definite than between it and meteorological phenomena. At Greenwich and elsewhere, delicately suspended magnets have their positions automatically recorded throughout the day and year. An examination of these records shows that the magnets are continually wobbling from side to side, and when successive years are

taken, the variation from the true or average direction is found to become greater as sun-spots become more frequent, to reach a maximum size after a maximum of solar activity and then to diminish as the spot-cycle dies out. The two cycles run together so intimately that the connection between magnetic variation and sun-spot frequency can hardly be denied. This being so, a necessary consequence would seem to be that violent solar disturbances, which give rise to large sun-spots, should be followed by irregular variations of the earth's magnetism, and should give rise to "magnetic storms." And in a few cases the expectation has been realised. The large spot of February 1892 caused a great commotion among the delicate instruments of magnetic observatories, and a few other large spots have provoked similar disturbances. The sun has thus been "caught in the act" of stirring up terrestrial magnetism. But many large spots have appeared without causing the magnets to flutter, while, on the other hand, violent oscillations have frequently been recorded when only a few small spots were visible on the side of the sun turned towards the earth. It seems, therefore, that the connection between individual spots and magnetic storms may be mere coincidences. Certain it is that the sun exerts an influence of some kind upon the earth, but the influence is not in strict proportion to the number or size of the spots visible at a particular time.

The aurora borealis is caused by electrical discharges in the upper regions of the earth's atmosphere. Magnetic storms are generally accompanied by auroral displays, and *vice versa*. What is more, the frequency of aurorae keeps time with the frequency of sun-spots, and therefore with the intensity and magnitude of magnetic variations. The facts show indubitably that there is a general relation between sun-spots, terrestrial magnetism, and terrestrial electricity,

s exhibited by observations of auroræ, but the nature of he connection has not yet been satisfactorily worked out. And here the opportunity is taken to correct an error which occurs in almost every book on astronomy. In 1859 wo well-known observers, working many miles apart, simultaneously saw two brilliant objects appear upon the sun, near the edge of a sun-spot. The luminous balls travelled through a distance of about thirty-six thousand miles across the sun in five minutes and then disappeared. In all probability, the phenomenon was caused by the fall of two large masses into the sun. Now, there is no doubt as to the accuracy of the observation, but the statement that the outburst was *immediately* followed by a magnetic storm does not appear to be founded upon fact. Nevertheless, this is the assertion usually made, one writer probably following another, and none looking up the authority. From an examination of the magnetic records kept at Kew, it appears that at the time of the observation the needles were unaffected, and it was not until *fifteen hours* after that a magnetic storm occurred. Brilliant auroral displays accompanied this storm and were doubtless connected with it, but the connection with the solar phenomena of nearly a day before can hardly be said to be established.

At certain intervals of time the moon comes between us and the sun and "eclipses" him. When this is the case, we are able to observe solar phenomena invisible to the unaided eye under ordinary circumstances owing to the glare of our atmosphere. Round the dark edge of the moon, scarlet coloured flames known as "prominences" or "protuberances" are seen to project. It was doubtful for a long time whether these prominences belonged to the sun or the moon, and the former body was proved to be the owner by the observation that they were slowly covered on one edge

of the sun and uncovered at the opposite edge, as our satellite changed its position. Solar prominences are parts of a stratum, to which the name of "chromosphere" is applied, consisting chiefly of hydrogen gas, which surrounds the photosphere. In the next chapter, description is given of an ingenious method discovered independently by Dr. Janssen and Prof. Lockyer in 1868, by means of which the chromosphere, and the prominences in it, can be studied at any time.

In addition to the prominences, a "glory" of pearly sheen is seen to surround the sun like a halo when the light of the photosphere is eclipsed. To this the name of "corona" is given. For a distance of about ninety thousand miles from the moon's edge the ring is extremely bright. Beyond this "inner corona" the "outer corona" extends in luminous streamers and sheets for distances reckoned in millions of miles, fading slowly and beautifully into invisibility. At one time astronomers inclined to the idea that the corona was not an actual solar atmosphere, but an optical effect produced by the earth's aerial envelope. That this is not the case is definitely established by two facts. In the first place, the corona has been analysed and found to consist partially of luminous gas; and secondly, photographs of the corona taken at different places during a solar eclipse have practically the same appearance.

Drawings of the same corona can hardly be regarded as furnishing any very definite information as to the form assumed at the time of observation. The discrepancy between the pictures drawn by two observers is frequently so great that it is difficult to believe the same phenomenon has been delineated. Photography has now almost entirely taken the place of visual observations of coronal forms, and its results can be relied upon to a greater extent. An in-

teresting fact, which comes out from an examination of the photographs which have been taken from time to time, is that the form of the corona is connected with the eleven-year sun-spot cycle. Thus, the photographs taken during the eclipses of 1871 and 1882, that is, at the times of sun-spot maxima, are very similar in character. The corona in each case had a very irregular appearance, and extended round the sun in luminous beams. The coronæ of 1878 and 1889—both years of minimum sun-spot frequency—are very similar to each other, but differ considerably from the form assumed during the maximum epochs. Extensions of the corona are seen over the sun-spot zones, and from the poles of the sun curved streamers project in very definite outlines.

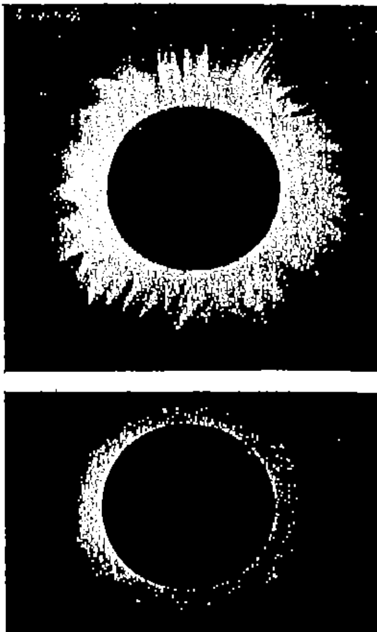


Fig. 8.—Variations in the apparent structure of the solar corona. The upper figure represents the corona of 1882; the lower (from a photograph by Professors Barnard and Pickering) shows the corona of 1889.

The sun dissipates its light and heat with a prodigality which characterises all nature. About 2,200 million times more heat and light is given out by the sun than is received by the earth, notwithstanding which all known substances

can be driven into vapour, in the focus of a powerful burning glass. And since it is impossible for the temperature at a focus to approach that of the source of heat, it must be concluded that the sun is very hot indeed, hotter than any furnace, hotter even than the electric-arc light. Our atmospheric envelope robs the sun's rays of much of their fierceness; nevertheless, the amount of heat received would melt every year a layer of ice surrounding the earth to a depth of forty yards. An impressive illustration of the intensity of radiation at the sun's surface is given by Professor Young. He says, "If we could build up a solid column of ice from the earth to the sun, two miles and a quarter in diameter, spanning the inconceivable abyss of ninety-three million miles, and if then the sun should concentrate his power upon it, it would dissolve and melt, not in an hour, not in a minute, but in a single second; one swing of the pendulum and it would be water, seven more and it would be dissipated in vapour" . . . . "to produce this amount of heat by combustion would require the hourly burning of a layer of anthracite coal, more than sixteen feet thick, over the entire surface of the sun—nine-tenths of a ton per hour on each square foot of surface—at least nine times as much as the consumption of the most powerful blast furnaces known to art." It has been calculated that, at this rate, the sun would burn out in less than six thousand years if composed of solid coal. But the sun's heat is not kept up by combustion—no "burning" goes on in the sense that we use the word. Two theories as to the manner in which the heat of our luminary is maintained are generally accepted by astronomers. One is that the sun is constantly being bombarded by meteorites, the result of the imparts being the development of heat and light. This doubtless is the case to some extent, but if meteorites fell into the sun in suffi-

cient quantity to keep up the present rate of solar radiation, they ought to make their presence clearly felt upon the members of our system. Another theory of solar conservation is that the sun is slowly shrinking in size. Such a contraction necessarily involves the development of heat, and it has been shown that the supply could be kept up by a yearly decrease of three hundred feet in the sun's diameter. A test of this theory would seem to be obtained by measuring the diameter of the sun year by year. But though astronomers are used to measuring very minute amounts, and optical instruments have almost reached perfection, it must be confessed that the sun would have to go on shrinking for nearly ten thousand years before his change of size would come within the bounds of detection. It seems very probable, however, that the shrinkage theory and the meteorite theory help one another in keeping up the supply.

The probable age of the sun is estimated by assuming that the shrinkage theory is correct. Granting this, it appears that he is about eighteen million years old, that he has passed the prime of life, and for about ten million years more will continue to radiate sufficient light and heat to support life as we now know it. Long before this time the human race will have disappeared, so no man will look upon the sun at "the last day."

Solar Statistics.

The following useful table of solar statistics is taken from Professor Young's standard work on "The Sun":—

Mean distance of the sun from the earth, 92,885,000 miles.

Variation of the distance of the sun from the earth between January and July, 3,100,000 miles.

Linear value of 1″ on the sun's surface, 450·3 miles.

Mean angular semidiameter of the sun, 16′ 2″·0.

Sun's linear diameter, 866,400 miles.

Ratio of the sun's diameter to the earth's, 109·3

Surface of the sun compared with the earth, 11,940.

Volume, or cubic contents, of the sun compared with the earth, 1,305,000.

Mass, or quantity of matter, of the sun compared with the earth, 330,000.

Mean density of the sun compared with the earth, 0·253.

Mean density of the sun compared with water, 1·406.

Force of gravity on the sun's surface compared with that on the earth, 27·6.

Distance a body would fall in one second, 444·4 feet.

Inclination of the sun's equator to the ecliptic, 7° 15′.

Mean time of the sun's rotation, 25·38 days.

Time of rotation at the sun's equator, 25 days.

"	"	latitude 20°,	$25\frac{3}{4}$	"
"	"	" 30°,	$26\frac{1}{2}$	"
"	"	" 45°,	$27\frac{1}{2}$	"

Linear velocity of the sun's rotation at his equator, 1·261 miles per second.

Intensity of sunlight at the surface of the sun, 190,000 times that of a candle flame, 5,300 times that of metal in a Bessemer converter, 146 times that of a calcium light, 3·4 times that of an electric arc.

Brightness of a point on the edge of the sun compared with that of a point near the centre of the disc, 25 per cent.

Thickness of a shell of ice which would be melted from the surface of the sun per minute, $48\frac{1}{3}$ feet.

Mechanical equivalent of the solar radiation at the sun's surface, continuously acting, nearly 10,000 horse-power per square foot.

Effective temperature of the solar surface, about 18,000° Fahr.

CHAPTER III.

THE ANALYSIS OF SUNLIGHT.

IN the whole domain of science there is no more wonderful achievement than that of determining the nature of the substances in the sun and stars. Fifty years ago, astronomers deemed the feat beyond the reach of human possibility. Since then, the science of celestial chemistry has been founded, with the "spectroscope" as its weapon of research, and the performances of the instrument have been so numerous up to the present that the whole of the previous astronomical knowledge becomes small in comparison. Especially is this the case with the sun. We see a luminous globe. Is it a white-hot ball of iron, or is its light similar to that of a glow-worm? What are the prominences which are seen to stud the corona during a solar eclipse? and the corona itself, of what is it composed? These are the kind of solar problems upon which the spectroscope has thrown light; and in this chapter we purpose describing the instrument which has opened up the new fields of inquiry, and some of the surprising results that have been attained.

But before going further, let us clearly understand the meaning of chemical analysis. The term signifies the breaking up of substances into their component parts. If a current of electricity is passed through water, the liquid is decomposed or broken up into two gases known as oxygen and hydrogen. By proper means, the two gases can

be caused to combine and again become water. Evidently, then, water is a compound substance formed by the union of oxygen and hydrogen. Now, whatever we do to each of these gases, whether we heat it, or pass electricity through it, or subject it to any force whatsoever, nothing but oxygen or hydrogen can be obtained. We have reached the parts of the liquid which cannot be decomposed, and such parts are known as "elements." Gold is an element, for nothing but gold can be obtained from it ; so is iron, and lead, and sulphur; but salt is a compound, for it can be broken up into two elements known respectively as sodium and chlorine.

There are thousands of different kinds of substances upon the earth, but chemists find that they are all combinations of seventy-five elements, many of which are extremely rare. This is not very strange after all. The thousands of words in our language are all compounds or combinations of the twenty-six letters of our alphabet. Chemical compounds are therefore analogous to words, and the elements that form them are analagous to the alphabet. A compound containing two elements is similar to a word of two letters, one into the composition of which three elements enter is like a word of three letters, and so on. Now, the chemical analysis of a substance means the determination of the elements which exist in it. How this end is attained by the chemist does not concern us here. The point to be brought out is that a portion of the substance has to be taken into the laboratory and subjected to all kinds of processes before a chemist is able to give an opinion upon it. But we cannot obtain a sample of the sun or a star to work upon, hence it would appear that no amount of searching could enable us to find the elements existing in these bodies. Incredible as it may seem, celestial chemistry is an accom-

plished fact. It is not at all necessary to send chemists prospecting into space, and to bring back portions of the worlds they visit. The spectroscope furnishes a means of analysing bodies by the light they emit; it enables astronomers to analyse the beams of light continually sent to us by the sun and stars, and to say to what elements each ray belongs.

Everyone has seen the pretty colours produced when sunlight is shining upon the lustres of a chandelier. Each pendant piece of cut glass forms a band coloured like the rainbow. Sunlight, then, is not an elementary colour, but can be broken up into a number of different colours. Let us investigate this more closely, using a large lustre, or a wedge-shaped piece of glass known as a "prism," for the purpose. The prism is placed in the path of a beam of sunlight entering a dark room through a round hole so that the rays fall upon one of its faces. Two facts will be noticed with regard to the beam when it has passed through the prism. In the first place, instead of keeping in its original direction, the beam is bent or refracted towards the base of the prism, and next, different colours are bent by different amounts, the result being that a coloured ribbon, known as a "spectrum," is produced. The colour least bent is red, then follows orange, then yellow; the next is green, the next blue, the next indigo, and the most bent colour of all is violet. These tints always preserve the same relative positions, that is, they always follow each other in the same order. If the red colour is subtracted from the beam before it falls upon the prism, no red appears in the spectrum, and the same applies to any other colour. In fact, the coloured band is produced by the overlapping of a large number of different coloured images of the hole through which the beam enters. Now, if you place seven

pieces of glass, coloured respectively red, orange, yellow, green, blue, indigo, and violet, in a line, so that one overlaps the next, each of the colours produced by the overlapping will be a mixture of two. If, however, the glasses are placed side by side in a row, no such impurity of tint is caused. In a similar manner, the overlapping of the images of the hole, which admits sunlight to the prism, causes the spectrum to be "impure." Each elementary tint should be ranged by the side of the next, passing by insensible gradations from the deepest red to the darkest violet. To obtain this result, a fine crevice or slit is employed instead of a hole. A slab, instead of a rod of light, falls upon the prism, and a spectrum, in which an infinite number of shades are ranged side by side, is produced. We are thus furnished with an accurate scale of colour, which can be viewed with the naked eye or through a small telescope. In a spectroscope, the slit for admitting a beam of light, the prism for decomposing the light, and the telescope for viewing it, are arranged in a compact form. The accompanying illustration shows such an instrument in its simplest form. The tube upon which the maker's name is marked has a slit at the end away from the prism, and the other tube is the view-telescope. We have said that the instrument is used to analyse light. Many substances, when burnt, have such distinctive colours that no instrument is needed to discriminate them. Thus, common salt or soda tinges the flame of a spirit-lamp yellow. Red fire, or a red Guy Fawkes' match, owes its colour to the presence of a chemical containing the element strontium; green fire, or a green match, contains the element barium. Hence, when we see a red firework or a green-coloured one, we are able to state, with more or less certainty, that strontium or barium is being burnt. But this can by no means be applied

to celestial bodies. The sun is a glowing mass, and, as far as observations with the unaided eye are concerned, it could be a ball of iron, or of gold, or of silver, or anything else. We cannot determine the quality of his light in the way that we did in the case of the fireworks. Indeed, only a few coloured fires can be distinguished in this manner. Generally half-a-dozen or more powders are mixed together, and the light they give when ignited is a mixture in which the colours due to individual elements are

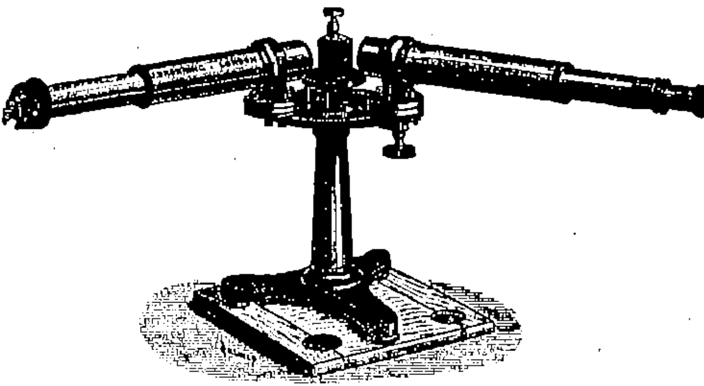


Fig. 9.—The Student's Spectroscope.

lost. The spectroscope here comes to our assistance. The yellow light due to the burning of common salt is caused to illuminate the slit of the instrument it falls upon, and traverses the prism and forms a yellow image. When observed with the view-telescope, the image is seen to consist of two fine yellow lines, very close together. Now let the red light of strontium fall upon the slit. It traverses the prism and forms red images—images not so much bent out of the original direction as the previous ones, and a

blue image, that is, one more bent. The light of burning barium causes a large number of brilliant lines and bands to be seen, some more bent and some less bent towards the base of the prism than the yellow lines exhibited by common salt. Lithium shows a red line—a line less bent out of the original direction than any of the others. A very good form of spectroscopic lamp is that shown in the figure. It consists of a burner and a dip for holding substances on a single stand. If a number of materials are burnt together in a flame of this character, each of them shows the same lines or bands as they do when burnt separately. The prism assigns particular positions to be taken up by the light of each element, and an observer soon gets to know these positions. He is then able to distinguish the lines or badges of different substances in much the same way that a military man can pick out soldiers of different regiments during a review. Different elements, then, exhibit different sets of lines when observed with the spectroscope. Some elements show only one or two lines, while others show a large number under similar conditions, but each element has a set of its own, whether the lines are few or numerous. This fact can be utilised to determine the elements in a mixture. The substance which it is desired to analyse is burned in a flame of some kind, and then observed through the spectroscope. "Yes," says the observer, "there are the lines of sodium, close to them are the

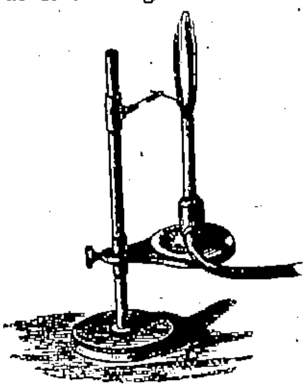


Fig. 10.—A Spectroscopic Lamp.

strontium lines, and there is the green line of thallium;" and he continues his observations in this manner until the origins of all the lines have been recognised.

When a gas flame, or the light of an ordinary lamp, or the incandescent ball of lime used for lantern illustrations is observed with a spectroscope, an unbroken band of colour known as a "continuous spectrum" is seen. The light of every white-hot solid or liquid body, or of any luminous gas under pressure, is transformed by the prism into this rainbow-coloured band.

We have said that a little salt placed upon the wick of a spirit-lamp tinges the flame yellow and causes a pair of bright lines—the "sodium lines"—to be seen in a spectroscope. If, while the lines are "on view," a lime-light is started, so that its bright beams have to pass through the sodium flame to reach the slit of the spectroscope, they will be seen not *bright* as before, but as *dark* lines upon a continuous spectrum. Turn off the incandescent light, or block it out by means of a screen, and the sodium lines will again be seen bright and alone. The flame is not altered by the light passing through it. We must therefore conclude that the lines are seen dark by contrast with the bright continuous spectrum of the lime-light. By placing lithium, or thallium, or any other substance upon the flame, and passing the beams from the incandescent cylinder of lime through it, each set of lines is seen dark upon a coloured ribbon instead of appearing as bright and differently coloured images of the slit. Thus, each element burning in the flame blocks out from the continuous spectrum the lines of which its own spectrum consists. This is a most important observation; indeed, it is the cardinal principle of spectrum analysis applied to the heavens.

In 1814, Fraunhofer, a German optician, found that by admitting sunlight to a prism through a crevice in a window blind, and viewing the spectrum with a small telescope, the coloured band was crossed by a number of dark lines at right angles to the direction of its length. He counted

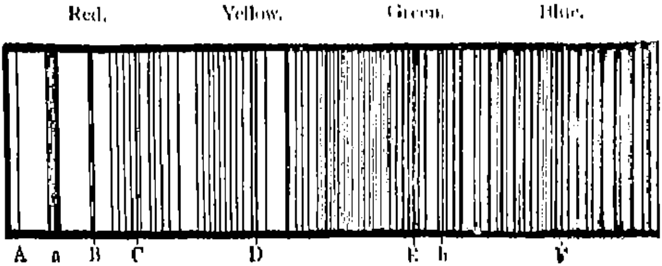


Fig. 11.—The Solar Spectrum mapped by Fraunhofer.

about six hundred lines, and mapped the positions of something like half this number, designating the most conspicuous lines by letters of the alphabet. With the spectroscopes now at the disposal of astronomers, thousands of dark lines can be seen in the spectrum of sunlight. In honour of the discoverer, they are termed "Fraunhofer lines." Fraunhofer found that the line, or rather pair of lines, produced by burning common salt, occupied exactly the same position as a dark line in the solar spectrum, but the circumstance was regarded more as an accident than otherwise. Not until nearly half a century later, in 1859, was the key to these enigmatical lines discovered. It is involved in the third principle experimentally illustrated above and enunciated by Kirchoff. What Kirchoff said in substance was this: "There is a solid or a liquid something in the sun giving a continuous spectrum, and around this are vapours of sodium, of iron, of calcium, of chromium, of barium, of magnesium, of nickel, of copper,

of cobalt and aluminium; all these are existing in an atmosphere, and are stopping out the sun's light. If the sun were not there, and if these things were observed in an incandescent state, we should get exactly these bright lines from them." (Lockyer.)

The conviction is thus forced upon us that the dark lines in the solar spectrum are caused by light from a very hot body having a continuous spectrum passing through an envelope of gases at a lower temperature. Each gas subtracts from the continuous spectrum those rays of which its own spectrum consists, hence, by matching the dark lines in the solar spectrum with bright lines of terrestrial elements, we can determine the chemical constitution of the atmosphere which produces them. The comparison is best made by burning substances in the electric arc, for we then see them at a temperature approaching that of the sun. Sunlight is caused to illuminate one half of the slit of the spectroscope, while the light of the arc illuminates the other half. The solar spectrum and the "arc-spectrum" of the substance being burned, are then seen one above the other, and the coincidence or non-coincidence of dark lines of the former with the bright lines of the latter can be made out. But the photographic plate has now almost entirely replaced eye-observations of this kind. The two spectra are caught upon a sensitised film, and the lines leave their impressions. The pictures can then be examined at leisure to see if Fraunhofer lines are matched by lines due to the substance burning in the electric arc.

The visible solar spectrum is a coloured band extending from red to violet, and as in many other things, we are apt to conclude that this strip represents the beginning and the end of it. But if a photographic plate is placed so that one end lies in the red part of the spectrum and the other

reaches beyond the violet, and after being exposed for a short time, it is taken away and treated with chemicals in the usual manner, what do we find? Lines more bent than the violet end of the spectrum appear upon the photographs, that is, lines which are utterly invisible to the eye. The lines in the violet and blue parts of the spectrum are also portrayed in their proper relative positions, but unless the film has been specially prepared, none of the lines from the green to the red are found upon the pictures. The photographic plate is thus sensitive to light rays which are incapable of producing any visual effect, and the eye, on the other hand, can see rays which leave no impression upon an ordinary sensitive film. We shall have occasion to refer to this point again.

Photographic and visual comparisons of the kind indicated above have shown the disciples of the "new astronomy" that most of the elements existing upon the earth are to be found in the sun. More than two thousand lines contained in the spectrum of iron coincide with the same number of dark lines in the solar spectrum. What is more, brilliant lines of iron are represented by conspicuous Fraunhofer lines; while faint lines in the spectrum of the metal have faint counterparts. According to the most recent observations the common terrestrial elements at present known to enter into the sun's constitution are, *calcium*, *iron*, *hydrogen*, *sodium*, nickel, *magnesium*, cobalt, *silicon*, *aluminium*, titanium, chromium, manganese, strontium, barium, carbon, copper, zinc, cadmium, silver, tin, lead, and *potassium*. The eight italicised elements make up rather more than fifty per cent. of the crust of the earth. There is little doubt that if the earth were heated to the temperature of the sun its spectrum would closely resemble the solar spectrum.

It was at one time thought that the Fraunhofer lines are

produced by absorption in our own atmosphere and not in the solar envelope. If this were so, the lines should increase in strength when sunlight traverses a greater thickness of atmosphere, that is, in the morning or evening. There should be a gradual decrease in intensity from sunrise to noon, and an increase from noon to sunset. A few lines really show this variation. They are, therefore, produced by our atmosphere, and are known as "telluric lines."

So far we have dealt only with the summation, as it were, of solar light. In 1866, Norman Lockyer suggested that different parts of the sun should be examined in order to obtain an intimate knowledge of solar phenomena. An image of the sun, formed by means of a lens, is caused to fall upon the slit of a spectroscope. Suppose it is desired to observe the spectrum of a sun-spot, the sun's image is arranged so that the spot is on the slit. Upon observing the solar spectrum when this is the case, a dark strip is seen to stretch from one end to the other. Many of the Fraunhofer lines are seen to be thickened or widened where the dark strip crosses them, while others are unaffected. We have seen that the lines owe their existence to the absorbing effect of a comparatively cool envelope. If, therefore, the amount of absorption is increased, the lines must appear wider. Hence the widening of Fraunhofer lines where the dark strip crosses them is an indication of increased absorption, and this can be produced either by a decrease of temperature or an increase of pressure, or both. By observing the set of lines that are affected, the kinds of vapours existing in the spot are determined. Occasionally, Fraunhofer lines in a spot-spectrum become suddenly bright, thus indicating that the vapours they represent have been suddenly increased in temperature or decreased in temperature.

The spectroscopic observation of prominences during the total solar eclipse of 1868 showed that these fantastic forms chiefly consist of glowing hydrogen, the most conspicuous lines in their spectrum being due to this element. Fortunately for science, Dr. Janssen and Prof. Lockyer independently discovered a means of observing prominences at any time. The principle of the method is as follows:—

We are unable to see the stars in the daytime on account of the glare of sunlight in our atmosphere, and the prominences and corona are invisible under ordinary circumstances for exactly the same reason. Strip the earth of its aerial envelope, and the stars, prominences, and corona could be seen against the dark background of space. Evidently, then, if the intensity of the atmospheric glare can be diminished without a corresponding diminution of the light of the prominences, these red flames will become visible. The spectroscope permits this to be done. The spectrum of diffused sunlight is the same as that of the sun itself. If an instrument having a single prism is used to view this spectrum, the characteristic coloured ribbon of light is seen. With a two-prism spectroscope the ribbon appears of a greater length, but fainter in all its parts; a three-prism instrument shows it stretched still more, but the stretching has again been accompanied by a loss of brightness. Thus the intensity of the spectrum of diffused sunlight diminishes as a spectroscope is increased in power. Now the spectrum of the glowing hydrogen prominences consists of a few bright lines. When observed with a single-prism spectroscope, these lines occur at certain distances apart. A two-prism instrument separates the lines to a greater extent, without altering the relative distances. A three-prism instrument makes the intervals still greater, and so on for any number of prisms, each adding its separative

effect to the one before it. It appears, then, that an increase of the power of a spectroscope diminishes the intensity of atmosphere glare, without diminishing the brilliancy of the bright lines of which the prominence spectrum consists. Hence, if the slit of a powerful spectroscope is placed near the sun's edge, so that the continuous spectrum seen is that of the sky and not of the sun itself, and a prominence happens to exist at that part of the edge, the bright lines in its spectrum will be clearly seen, and if

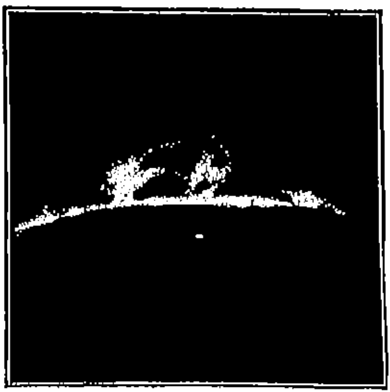


Fig. 12—A Solar Prominence, photographed by Prof. Hale in full daylight.

the slit is widened, the prominence itself becomes visible. In order to observe the prominences projecting from the sun's disc at any time, the slit of the spectroscope has to be adjusted at different points until it has been taken completely round the edge. By an invention due to Prof. Hale of Chicago, all the red flames shooting out from the edge can now be photographed at a single exposure. The sun is artificially eclipsed and photographed, and the

clouds of glowing hydrogen which float above it at the time are delineated upon the resulting picture.

The prominences are conveniently arranged into two groups, known respectively as "quiescent" or "hydrogen" prominences, and "eruptive" or "metallic" prominences. The former class resemble our terrestrial clouds. They are usually very large, extending to a height of 50,000 or 100,000 miles above the atmosphere, and frequently endure unchanged for days together. Prominences of the latter class are far more vivacious than their steady-going brethren, and are less massive. They exhibit many bright lines due to metallic elements, hence the designation "metallic prominences." Prof. Young remarks with regard to these flames, "They usually appear in the immediate neighbourhood of a spot, never occurring very near the solar poles. Their form and appearance change with great rapidity, so that the motion can almost be seen with the eye—an interval of fifteen or twenty minutes being often sufficient to transform, quite beyond recognition, a mass of these flames 50,000 miles high, and sometimes embracing the whole period of their complete development or disappearance. Sometimes they consist of pointed rays, diverging in all directions, like hedgehogs' spines. Sometimes they look like flames, sometimes like sheaves of grain, sometimes like whirling waterspouts capped with a great cloud; occasionally they present most exactly the appearance of jets of liquid fire rising and falling in graceful parabolas; frequently they carry on their edges spirals like the volutes of an Ionic column, and occasionally they detach filaments which rise to a great elevation, gradually expanding and growing fainter as they ascend until the eye loses them."

The motion of a prominence shot straight out from the sun's edge can be seen, but it is evident that if the flame were

moving towards or away from us at the same time, or if it had a whirling motion, the eye could not perceive it. Fortunately, this "motion in the line of sight" can be detected and measured by means of the spectroscope. The principle is as follows:—

When standing upon the platform of a railway station towards which an express train is approaching, many people will have noticed that the pitch of the whistle *increases* slightly as the engine approaches, and *decreases* as it whirls away. The absolute pitch of the whistle is immaterial. When the distance is diminishing, the pitch is raised, and when the distance is increasing, the pitch is lowered. This principle also applies to lights. A luminous body approaching the earth has its colour-pitch raised, while a motion away from the earth causes it to be lowered. The positions of lines in a spectrum corresponds to the pitch of notes in the musical scale. The lowest notes of a piano correspond to red light, and the highest notes to violet light. Further, each C of the piano is analagous to a line of hydrogen in the solar spectrum. Now the difference between the pitch of C and any other note is constant. If the piano is moving rapidly towards us, or we towards it, and all its notes are sounding, all of them will have their pitch raised, while a motion in the opposite direction causes a lowering of pitch. But if we suppose that one set of notes, say C and all its octaves, is being hurried towards us while the remainder are at rest, this set only will have its pitch increased. The difference of pitch between each C and the D next above it will therefore be diminished, and the magnitude of the difference will depend upon the velocity with which the C notes move towards us. A motion of recession causes a lowering of the C notes relatively to those at rest. Now transfer your thoughts from the musical notes

to the hydrogen lines in the spectrum of a prominence. If the hydrogen to which they owe their being is moving towards the earth, the lines are increased in pitch, they are shifted slightly towards the Fraunhofer lines just above them, that is, nearer the violet end of the spectrum. Hydrogen moving away from the earth suffers a decrease of pitch, and the difference of distance between its lines and the lines nearer the red end of the spectrum is diminished. By measuring the difference on either side, the velocity of approach or recession of the mass of hydrogen can be calculated. Similar reasoning applies to

Fig. 13.—Changes observed by Young in a hydrogen line of a sun-spot spectrum.

the spectrum of a sun-spot. It sometimes happens that many of the Fraunhofer lines are considerably distorted in a spot-spectrum. Thus, the lines of hydrogen, instead of being straight, assume zig-zag and branching shapes. Where the lines are bent towards the red end of the spectrum, the hydrogen they represent must be moving away from the earth, and, on the other hand, the parts of the spot in which the gas is moving towards the earth show

the hydrogen lines displaced in the opposite direction. It is only when the gas is neither approaching nor receding from us that "the crooked is made straight."

Both in prominences and sun-spots a whirling motion has been detected indicating that the sun, like the earth, has its "cyclones" and "tornadoes," but on a much grander scale. The velocities shown by the spectroscope in solar phenomena are usually from fifty to about two hundred miles per second, and occasionally a rate of three hundred miles per second is measured, but this is very rarely exceeded. It is difficult to conceive of material ejected with these tremendous velocities, yet the spectroscope shows clearly that the masses of gas do actually move in this swift manner. As to the nature of the forces which produces this violent agitation, little is definitely known.

Metallic prominences are closely connected with sun-spots. They occur most frequently over the sun-spot zones, wax and wane in an eleven-year period, break out in high latitudes after a minimum of activity, and then approach the equator up to the next minimum. Indeed, all solar phenomenas are connected in some way or other; and as time goes on, the law that governs them will be revealed.

The spectroscope has been turned to the corona during the brief moments of solar eclipses, and the bright lines seen and photographed show at once that we are dealing chiefly with a luminous gas. The spectroscopic trade-mark, so to speak, of the corona is a green line coincident with a faint Fraunhofer line in the ordinary solar spectrum. Like many other lines, this has not been matched with a line given by a terrestrial element, that is to say, no known element has a line in exactly the same position as the "corona line." The probability is that the line is due to a material lighter even than hydrogen, the lightest of known

substances. The extremely fine, indeed, one may say, the ghostly texture of the corona, shows that the material exists in a state of excessive tenuity.

In addition to the conspicuous badge of the corona, a number of other bright lines, some of which are due to hydrogen, show themselves in the spectrum. A number of dark Fraunhofer lines and a faint continuous spectrum are also seen. This indicates that some of the coronal light is sunlight reflected by solid particles. But since no method has yet been perfected whereby this envelope or outer atmosphere can be studied in daylight, less is known about it than the prominences, which, as has been pointed out, can now be studied without waiting for an eclipse.

The physical constitution of the sun, and the cause of the various solar phenomena, have been and are still matters of discussion. The general belief is that the *nucleus* of the sun consists of gases under great pressure and at extremely high temperatures. Surrounding this is the *photosphere* or luminous surface, which is probably of a cloudy nature, but the clouds instead of being composed of particles of water consist of condensed vapours of metals. The clouds float in an atmosphere in which uncondensed vapours of metals take the place of the oxygen and nitrogen of our own atmosphere. The atmosphere extends above the level in which the photospheric clouds occur, and, by its absorbing action, produces the Fraunhofer lines in the solar spectrum. *Faculæ* are elevated clouds, and they appear brighter than the general photosphere, because their light has not to pass through such a great thickness of absorbing atmosphere. Spots are cool depressions in the photosphere. They are probably produced by the downrush of large quantities of condensed matter upon the photosphere. The *granules* are the tops of photospheric clouds. The *chromosphere* extends

to a height of about 5,000 or 10,000 miles above the photosphere.

The appearance of this scarlet-coloured shell "is as if countless jets of heated gas were issuing through vents and spiracles over the whole surface, thus clothing it with flame, which heaves and tosses like the blaze of a conflagration." (Young.) The chief constituents of the chromosphere are hydrogen, and an unknown substance to which the name of "helium" has been given. The *prominences* are portions of the chromosphere which have ascended above the general level. Surrounding the chromosphere, the *coronal atmosphere* or *corona* occurs. This envelope consists partly of glowing gas and partly of solid particles, which reflect sunlight. Its chief gaseous constituent is unknown in terrestrial chemistry, and has been named "coronium."

Much has been done since the spectroscope entered the field of inquiry, but much more remains to be done. The "stream of tendency" is towards solar physics, and facts are being rapidly accumulated, which, though apparently unimportant, must bring us nearer to the "first cause."

CHAPTER IV.

THE EARTH'S CLOSE COMPANION.

THE moon is the earth's obsequious attendant. She is bound to us by the strong attachment of gravitation, and accompanies us wherever we go. Her distance is only 240,000 miles, that is, about ten times greater than the circumference of the earth, and four hundred times less than the sun's distance. Judging by appearances, the full moon looks almost as large as the sun, but there is such a difference between the distances of the two bodies from the earth, that it must be concluded that the moon is really much smaller than the sun. The apparent sizes of objects are proportional to the distances from which they are viewed. Since, then, the moon is seen from a distance four hundred times less than the distance of the sun, and appears approximately to have the same diameter, her real diameter is four hundred times less than that of the sun, that is, one four-hundredth of 866,000 miles, or 2,165 miles. From this it will be seen that the moon is almost a nonentity compared to the sun. A striking illustration of her insignificance is afforded by the fact that if the earth could swell in size until it reached the moon, 240,000 miles away, its diameter would only be a little more than half the sun's diameter.

The moon is a small body even when compared with the earth. About three and a half moons in a row would reach from England to the Antipodes through the centre of the

earth. Americans can realise with exultation that North and South America taken together have more square miles than the whole of the lunar surface. As regards the volume or bulk, forty-nine moons welded into one would make a globe of the same size as the earth. But this globe would only weigh about three-fifths as much as the earth, for the lunar rocks, taken as a whole, are not so dense as those which make up our planet. If both lunar and terrestrial materials had the same average density, the earth's mass would be forty-nine times greater than the moon's, as well as its volume, whereas the mass of the earth is eighty-one times greater than that of the moon.

"The man in the moon," if endowed with the same muscular exertion as ourselves, would be able to perform prodigious feats. If he could carry one hundredweight on the earth, he could carry six hundredweight on the moon, and if he could jump three feet here below, he could with the same exertion leap eighteen feet on the moon. Should he turn the scale at twelve stone on the earth, and be transported to the moon, he would find that the change of place had brought his weight down to about twenty-eight pounds. Suppose communication had been opened up between the earth and the moon, and we supplied the inhabitants of our satellite with coals to cheer their dreary lives. A ton of coals, containing the usual quantity of 20 cwt., is started on its journey. It reaches the anxious householder on the moon, and he decides to check the weight by means of a spring-balance recently imported from the earth. The re-weighing would lead the lunarian to doubt the probity of terrestrial coal merchants, for he would find that the coals only weighed 3 cwt.

The moon differs from the sun in the fact that it passes through phases or changes. First, the "New moon, like a

silver bow, new bent in heaven," is seen just above the sun as he sets on the western horizon, the horns of the crescent always being pointed away from the globe from which her light is borrowed. Each night sees the crescent wider, and soon the half moon is reached. A week later the full moon "rolls through the dark blue depths." Another week and a half moon is again visible, then a crescent is seen in the dawn, with the horns pointing away from the sun, and then the old moon is swallowed up in sunlight. The time from full moon to the next, or from any phase to the same phase again, is 29½ days. From new moon to half moon, half to full, and so on, the intervals is, roughly speaking, seven days, and there is little doubt that our week of seven days had its origin in this fact.

If the moon is observed near a particular star at any time, she will be found in the same relative direction after 27⅓ days. This interval is known as a sidereal or star month.

Lunar phases result from the fact that moonlight is reflected sunlight. One half of the moon is bathed in the sun's beams, while the other half is in utter darkness. When the illuminated half is facing us, the moon is full, when we view it sideways, a half moon is seen, and when the bright face is turned from us, we see no moon at all. All the changes are caused by the ever-varying aspects presented to us by the hemisphere of the moon which faces the sun.

At the time of new moon our satellite is in "conjunction" with the sun, that is to say, both bodies appear due south at the same instant. Usually the moon is slightly above or below the sun at the time of conjunction, so she does not come between us and his genial beams. The illuminated side is then turned away from us. A few days later, the moon has moved round the earth sufficiently to show a small portion of her bright side. Seven days after new

moon, the first quarter of the monthly journey has been described. At this time our satellite crosses the earth's orbit, and we are able to see one half of the illuminated hemisphere. Seven days more, and the moon is in "opposition" with the sun, that is to say, the sun, earth, and moon are in one direction, with the earth in the middle. But the three bodies are not generally in a line, so the people on the dark side of the earth are able to see the moon "in full-orbed glory," as the sunlight streams upon her face, and clothes her with radiance. At the end of the third quarter, the moon is once more in a direction at right angles to the sun, and a half moon is seen. From this time the visible portion of the lunar surface diminishes to new moon, when the cycle of changes begins again.

If the moon revolved round the earth in the same plane—the plane of the ecliptic—as that in which the earth journeys round the sun, then once a month she would come between us and the sun and eclipse him, that is to say, an eclipse of the sun would occur at the time of every new moon. Similarly, at the time of each full moon, the sun, earth, and moon would be in a straight line, and an eclipse of the moon would occur as our satellite passed into the earth's shadow. These events do not happen monthly, because the moon does not revolve on exactly the same plane as the earth. By observing the moon's track among the stars, it will be found not to coincide with the sun's track—the ecliptic. Could two luminous trails be drawn upon the sky to represent the respective paths of the "greater and lesser lights," they would be seen to cross one another at two points, known as "nodes." The greatest distance between the two trails would be about ten times the apparent diameter of the moon. Now it should be evident that a total eclipse can only happen when the moon is at one of

the points where her orbit cuts the ecliptic. If the sun should arrive at this point at the same time as the moon, a solar eclipse must occur; if the moon should arrive at a node just when the earth's shadow is sweeping past it, she must be totally eclipsed, and if the three bodies should be in a line when the moon is near, but not at a node, the eclipse will be only partial.

It was noticed in very early times, that after an interval of 223 lunar months, eclipses happened in the same sequence as before; in other words, the occurrence of eclipses follows a cycle of this length. The period is known as the "Saros," and by means of it the dates at which eclipses would occur were predicted by ancient astronomers. Thus an eclipse which happens on any particular day will occur again after 223 months, or, more accurately, 6,585$\frac{3}{4}$ days. In the whole period there are about forty-five solar and twenty-five lunar eclipses. Seven eclipses can occur in a year, and two must occur; in the latter case, both are eclipses of the sun.

The periodical recurrence of eclipses is caused by a movement of the nodes of the moon's orbit. Reverting to the imaginary luminous tracks of the sun and moon, suppose that the two crossed each other at one point exactly in front of a star. At the end of a month, the node would be found to the west of the star; in two months, it would be further to the west, and so on. After nineteen years, the nodes would have backed completely round the ecliptic, and would be projected upon exactly the same part of the sky. And when it is remembered that eclipses only happen with the moon near a node, it will be understood that the length of the lunar cycle of 223 months must be regulated by the motion of the nodes.

The phenomena of a total solar eclipse have already been

described. It sometimes happens that the moon's apparent size is smaller than the apparent size of the sun at the time of eclipse. Our dark companion cannot then cover up the whole of the sun's disc, so a luminous ring is seen surrounding her. This is known as an "annular" eclipse.

An eclipse of the sun can only be seen where the moon's shadow touches the earth, and the average width of this shadow is about 200 miles. On this account, it is very rarely that a little spot like England lies in the track of the shadow. The next total eclipse visible in our own country will not occur until 1999. On April 16th, 1893, there was a total eclipse of the sun; and it was utilised by astronomers to elucidate some of the many unsolved solar problems. The shadow-track crossed South America from Chili to Brazil, entering Africa near Bathurst, and left the earth in the interior of the Dark Continent. The eclipse did not come to English astronomers, so they went to it. For nearly five minutes the sun was completely covered by the moon, and darkness enshrouded like a pall the people over whom the shadow passed.

From the above explanation it will be seen that an eclipse of the sun can only happen at *new* moon. Information of this kind should be part of the stock-in-trade of a novelist. A very successful writer, whom it is unnecessary to mention, describes a solar eclipse which occurred the day after *full* moon, and to make matters worse, the eclipse was said to last for half an hour, whereas the longest possible duration of totality is less than eight minutes.

A total eclipse of the moon is always visible over more than half the earth, and has a duration of a couple of hours. The phenomena observed are not very striking. During totality, that is, when the moon is entirely immersed in the

earth's shadow, our satellite can be seen as a dull reddish-coloured disc. The earth is between her and the sun, so no direct sunlight can reach the lunar surface. From this it would seem that the moon is not a cold, dead world, but a globe at a dull-red heat. But this is not the case. The appearance is caused by the action of the earth's atmosphere in diverting the sun's beams from their course. Rays of light from the sun strike our atmosphere, and are bent towards the earth's conical shadow; they fall upon the moon in the shadow, and make its surface visible. In traversing the earth's atmosphere, and being reflected through it again from the lunar surface, sunlight is shorn of most of its original glory, and only dull red rays are left to report to us the story of the journey.

By the exercise of a little imagination, some of the grey markings visible upon the lunar surface are seen to bear a resemblance to a human face. According to an old legend, this "man in the moon" was transported from the earth for the heinous crime of picking up sticks upon a Sunday. A circumstance which has struck most people is that the same face is always visible. Sometimes we see a little more of one side or another, but the difference is hardly noticeable, and the dweller on our satellite seems to keep his longing eyes fixed upon the world from which he was torn. The moon, in fact, always keeps the same side towards the earth, and from this it would seem that she does not rotate or spin like the earth. She really does rotate, however, but very slowly, and just making a complete turn in the $27\frac{1}{3}$ days required to perform a revolution, that is to say, the moon's rotation and revolution periods are of the same length. It is somewhat difficult to convince people that the moon rotates, while, at the same time, we own that the other side is never seen. A simple experiment should dispel the doubt. Place a

globe or a ball of some kind upon a table to represent the earth, and near the wall of the room let a lighted lamp stand for the sun. Now walk round the table, keeping your face to the globe upon it, in the manner that the moon revolves round the earth. When on one side of the table you will face the lamp; when on the opposite side your back will be towards it. For this to occur, you must have turned half round in walking half the distance round the table. Make the other half of the journey, and you will again face the sun, having performed a rotation as well as a revolution. The same thing can be tangibly illustrated by tying one end of a long piece of thread to a button on the waistcoat and the other end to the lamp, and then walking round the globe as before. At the end of the journey, the thread will be found to encircle the body, thus clearly proving that the revolution has been accompanied by a rotation.

Sometimes we are able to see over the moon's north pole, and at other times a little beyond the south pole. Also twice a month we are able to see slightly round the moon's east and west edges. And further, rotation of the earth causes us to see the moon from different points of view. When she is rising, we look slightly over one edge, and at the time of setting we peer slightly over the opposite edge. These oscillations of the circle of illumination on the lunar surface are termed "librations." On account of their existence, fifty-nine per cent. of the moon's surface is visible at one time or another. The remaining forty-one per cent. is never seen by us, though it is illuminated by the sun like other parts of the surface. It is possible, and, indeed, very probable, that the unseen part of the moon is entirely different in structure from the part turned towards us.

Galileo, in giving an account of the celestial wonders

which had been revealed to him by means of the telescope, speaks first of the surface of the moon. Even in his small telescope our satellite appeared a beautiful object. In every age, dark markings had been seen discolouring the moon's face, but Galileo found numerous smaller spots never before seen by man. The words in which the father of physical astronomy states his first observations are full of interest. Galileo's "Sidereal Messenger: Unfolding Great and Marvellous Sights, and Proposing them to the Attention of Every One, but especially Philosophers and Astronomers," was published in 1610. The following extract is from Mr. Carlos' translation:—

"On the fourth or fifth day after new moon, when the moon presents itself to us with bright horns, the boundary which divides the part in shadow from the enlightened part does not extend continuously in an ellipse, as would happen in the case of a perfectly spherical body, but is marked out by an irregular, uneven, and very wavy line, for several bright excrescences, as they may be called, extend beyond the boundary of light and shadow into the dark part, and on the other hand pieces of shadow encroach upon the light; nay, even a great quantity of small blackish spots, altogether separated from the dark part, sprinkle everywhere almost the whole space which is at the time flooded with the sun's light, with the exception of that part alone which is occupied by the great and ancient spots. I have noticed that the small spots just mentioned have this common characteristic always, and in every case that they have the dark part towards the sun's position, and on the side away from the sun they have brighter boundaries, as if they were crowned with shining summits. Now we have an appearance quite similar on the earth about sunrise when we behold the valleys, not yet flooded with light, but the moun-

tains surrounding them on the side opposite to the sun already ablaze with the splendour of his beams; and just as the shadows in the hollows of the earth diminish in size as the sun rises higher, so also these spots on the moon lose their blackness as their illuminated part grows larger and larger. Again, not only are the boundaries of light and shadow in the moon seen to be uneven and sinuous, but, and this produces still greater astonishment, there appear very many bright points within the darkened portion of the moon, altogether divided and broken off from the illuminated crust, and separated from it by no inconsiderable interval, which, after a little while, gradually increase in size and brightness, and after an hour or two become joined on to the rest of the bright portion, now become somewhat larger, but, in the meantime, others, one here and another there, shooting up as if growing, are lighted up within the shaded portion, increase in size, and at last are linked on to the same luminous surface, now still more extended. Now is it not the case on the earth before sunrise, that while the level plain is still in shadow, the peaks of the most lofty mountains are illuminated by the sun's rays? After a while does not the light spread further, while the middle and larger parts of those mountains are becoming illuminated; and, at length, when the sun has risen, do not the illuminated parts of the plains and hills join together? The grandeur, however, of such prominences and depressions in the moon seem to surpass both in magnitude and extent the ruggedness of the earth's surface."

The description accurately represents and explains what is seen when the moon is viewed through a small telescope at the present time. Galileo, and other observers following him, looked upon the moon as another earth, of which "the brighter portion may very fitly represent the surface of the

land, and the darker the expanse of water." Though this idea is now known to be erroneous, the large dark patches retain the name of "seas."

Fig. 14.—Reduced copy of a photograph of the moon taken at the Lick Observatory. Inverted telescopic view.

The features of the lunar surface are conveniently grouped into five classes. There are craters which more or less resemble in appearance the craters of terrestrial volcanoes; the plains, covering about one half of the moon's visible surface; the mountain formations, analagous in some respects to the mountain ranges of the earth; rills or clefts which frequently run like deep trenches through plains and mountains for many miles, and bright streaks which radiate from some of the craters and are unlike anything on the earth.

The word "crater" is used to designate the circular cups

or cavities with which the moon's surface is pitted. They vary considerably in size, some being a hundred miles in diameter, while others are so small that they can only just be seen under the best conditions. But a family likeness runs throughout all of them. Each consists of a rampart or ring, rising sometimes to a height of three or four miles above the surrounding surface. Near the centre of the areas embraced by these circular walls, one or more conical peaks usually occur. In some craters, the peaks rise high above the inside level, known as the crater-floor; others are lower; only traces of central cones are seen in many craters, and there are craters having no mountain peaks at their centres.

Though lunar craters bear a general resemblance to the mouths of terrestrial volcanoes, there is one material difference between them. The floors of craters of volcanoes on the earth are generally above the level of the neighbouring country, while on the moon they are depressed below the level of the outside surface, the distance from the top of the rampart to the plateau within being frequently twice as great as that from the top to the bottom on the outside.

The origin of lunar craters is still a vexed question. One would conclude by analogy that the forces which cause volcanic eruptions on the earth have been at work on the moon. And when it is remembered that the intensity of gravitational attraction on our satellite is but one-sixth that on the earth, it can be understood that the ejected rock would be carried to a much greater distance from the vent than is the case with terrestrial volcanoes. The late Mr. Nasmyth made some valuable suggestions as to the mode of formation of lunar craters and walled plains. A lunar volcano in full activity could eject materials with such a force that they would reach the surface at a distance of several miles from

the pipe, and pile up a large rim round it. In the case of a volcano in feeble activity, the ejected rock would not be carried so far, so a rim of small diameter would be built up. As the volcanic action died out, fragments of rock would be so feebly ejected that they would fall round the vent and build up the central cone which characterises a normal lunar crater. Lava, or molten rock, might then pour out and more or less submerge the cone. Indeed, it is possible that the flow may continue until the central cones are overtopped and the molten rock reaches nearly to the rim of the crater. All these stages are represented by actual lunar formations. There are, however, many objections to this simple explanation, the chief being that there is no evidence of water on the moon. Some astronomers and geologists favour the idea that the craters must have been produced by the bombardment of masses of rock when the moon was in a viscous condition.

That the moon has practically no atmosphere is evidenced by several facts. In the first place the edge of our satellite is as bright and sharp as other parts of the disc, whereas if an atmosphere existed, it would be dim and hazy; and secondly, the shadows on the moon are always seen perfectly defined and black. Further, when the moon comes between us and a star, the latter disappears in an instant behind the sharp edge, and does not become slowly obscured as it would do if a lunar atmosphere came in front of it before the solid surface of the moon.

The temperature of the moon's surface must vary between very considerable limits. For about a fortnight the sun's beams beat upon the land untempered by any atmosphere. There is no vaporous blanket to soften the light and heat, or to prevent its loss from the lunar surface. And, as a result, it is found that the sunlit surface loses its heat so

rapidly that it is never above the temperature of freezing water. For about fourteen days the sun never shines on one side of the moon, and then the temperature must fall to a degree compared with which our Arctic regions would be tropical. Mr. Nasmyth remarks, "Among the consequences of the alternations of temperature to which the moon's crust is thus exposed are doubtless more or less considerable expansions and contractions of the surface material, and we may conceive that a cracking and crumbling of the more brittle constituents would ensue, together with a grating of contiguous but disconnected masses, and an occasional dislocation of them. We refer again to these phenomena to remark that, if an atmospheric medium existed they would be attended with noisy manifestations. These are abundant causes for grating and crackling sounds, and such are the only source of noise upon the moon, where there is no life to raise a hum, no wind to murmur, no ocean to brim or foam, and no brook to splash. Yet even these crust cracking commotions, though they might be felt by the vibrations of the ground, would not manifest themselves audibly, for without air there can be no communication between the grating or cracking body and the nerves of hearing. Dead silence reigns on the moon; a thousand cannons might be fired and a thousand drums beaten upon that airless world, but no sound would come from them: lips might quiver and tongues essay to speak, but no action of theirs could break the utter silence of the lunar scene."

LUNAR STATISTICS.

Diameter of moon, 2,163 miles, $\frac{1}{3\cdot66}$ of the earth.

Surface of moon, 14,657,000 square miles, $\frac{1}{13\cdot44}$ of the earth.

Solid contents of the moon, 5,276,000,000 cubic miles, $\frac{1}{49 \cdot 26}$ of the earth.

Mass of moon, 73 million tons, $\frac{1}{81 \cdot 40}$ of the earth.

Density of moon, $\frac{3}{5}$ of the earth.

Density of moon compared with water, 3·44.

Force of gravity at the moon's surface, $\frac{1}{6}$ of the earth.

Average distance from the earth, 238,840 miles.

Greatest distance from the earth, 252,970 miles.

Least distance from the earth, 221,617 miles.

Length of a lunar month, 29 days, 12 hours, 44 minutes, 27 seconds.

Length of a sidereal month, 27 days, 7 hours, 43 minutes, 11·5 seconds.

Area of the moon never seen, 41 per cent.

Area visible at various times, 59 per cent.

Inclination of axis to ecliptic plane, 87° 25′ 51″.

Inclination of orbit to ecliptic plane, 5° 8′.

Length of the Saros or eclipse period, 223 months, or 6,585 $\frac{1}{3}$ days.

The light of about 600,000 full moons would be required to equal the light of the sun.

The temperature of the moon's surface is never above 32° Fahr., and for days together is far below it.

CHAPTER V.

THE SUN'S FAMILY OF PLANETS.

THE planets are the earth's brothers and sisters, and the sun rules over all with despotic authority. Each planet is eager to escape into outer space, but the sun keeps a tight rein, and curbs the restive spirit. Should "the tie that binds" be broken, each member of our little family group would take walks in life very different from those they now pursue. But they are exercised into moving "decently and in order," and celestial anarchy is prevented by the firmness of the rule.

The nearest planet to the sun is Mercury, "the swift messenger of the gods," and remarkable for the vivacity of his motions. Then comes the bright and beautiful Venus. The earth follows. At a still greater distance Mars, "ruddy and awful," runs his race. Beyond him, our big brother Jupiter makes his stately march. And next Saturn moves, while "his steadfast shade sleeps on his luminous ring." Uranus, the father of Saturn, has a path suitable to his dignity, and last of all comes Neptune, moving in the infinite ocean of space.

The number of miles each planet is distant from the sun, and other numerical facts concerning the members of our system, are tabulated at the end of this chapter. It is sufficient here to give illustrations which will enable the relative dimensions to be grasped.

The earth is approximately eight thousand miles in diameter. Let us represent this by one foot and construct an imaginary solar system on the scale of one foot to eight thousand miles. St. Paul's Cathedral in London is known to be a mighty structure, and its dome, more than one hundred feet in diameter, is a fitting representation of a

hemisphere of the sun. Mercury would be proportionally represented by a baby's head at Chancery Lane; Venus, by a globe rather less than one foot in diameter revolving in a path at the distance of Charing Cross from the cathedral dome; the earth by a one-foot globe situated at Buckingham Palace; and the moon a cricket ball circling round her at a distance of thirty feet. Mars, a man's head, travelling in a circle having for its radius the distance from St. Paul's to South Kensington Museum; the minor planets or asteroids, small shot, revolving at the distance of Hammersmith; the radius of Jupiter's orbit would be just beyond Richmond, the planet itself being a globe eleven feet in diameter; Saturn, a nine-foot globe would be at Staines, near Windsor, and would move round St. Paul's at this distance; Uranus would be a four-foot globe at Reading; and Neptune, a globe four and a half feet in diameter, would have for the radius of his orbit the distance from London to Oxford. This is an accurate plan of the orbits of the planets and the sizes of the bodies themselves. On the scale adopted, namely, one foot to eight thousand miles, the nearest star has a distance of 500,000 miles. Sir John Herschel, in his "Outlines of Astronomy," gives the following illustration of the relative magnitudes, distance, and velocities of the planets. "Choose any well-levelled field or bowling-green. On it place a globe, two feet in diameter, this will represent the sun; Mercury will be represented by a grain of mustard seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus a pea, on a circle of 284 feet in diameter; the earth also a pea, on a circle of 430 feet; Mars a rather large pin's head, on a circle of 654 feet; the asteroids, grains of sand, in orbits of from 1,000 to 1,200 feet; Jupiter a moderate-sized orange, in a circle nearly half a mile across; Saturn a small orange, on a circle of four-fifths of a mile; Uranus a full-sized cherry, or small plum, upon the circum-

ference of a circle more than a mile and a half; and Neptune a good-sized plum, on a circle about two miles and a half in diameter. As to getting correct notions on this subject by drawing circles on paper or, still worse, from those very childish toys called orreries, it is out of the question. To imitate the notions of the planets in the above-mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus in 4 minutes 14 seconds; the earth in 7 minutes; Mars in 4 minutes 48 seconds; Jupiter in 2 hours 56 minutes; Saturn in 3 hours 13 minutes; Uranus in 2 hours 16 minutes; and Neptune in 3 hours 30 minutes."

The comparative diameters of planets can be graphically shown by lines of different lengths. A square constructed on each line represents relatively the area of the planet's surface, and a cubical box having sides equal in length to the diameter exhibits the proportional volume or bulk. A single diagram constructed in this manner shows at a glance the relative diameters, surface areas, and cubical contents of the eight large planets.

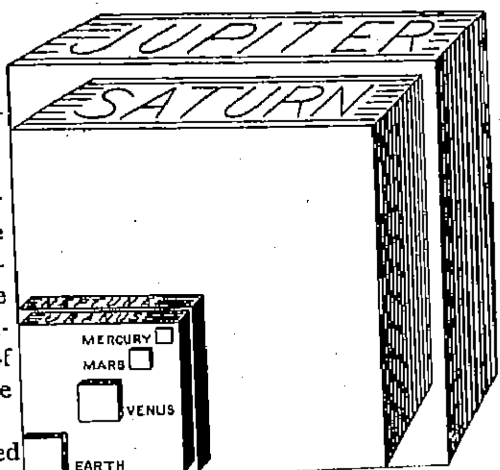


Fig. 15.—The relative diameters, surface areas, and cubical contents of the eight large planets.

The so-called weight of the earth is 6,000 millions of millions of millions of tons. If we represent

this inconceivable quantity by a weight of one pound, the mass of the sun would be 150 tons; Jupiter, 310 pounds; of Saturn, 93 pounds; of Neptune, 17 pounds; of Uranus, 14 pounds; of Venus, 13 ounces; of Mars, $1\frac{1}{2}$ ounces; of Mercury, 1 ounce; and of the moon, rather more than 3 drams. It will be seen from this that the sun considerably outweighs the planets, in fact, his mass is seven hundred and fifty times greater than all the planets put together.

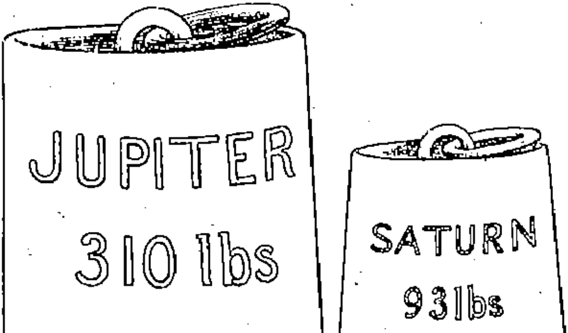


Fig 16.—Comparative masses of the moon and planets.

A planet's size and its mass determines the intensity of gravitational attraction at its surface. On this account, the same body, if weighed in a spring balance, would appear to have different weights on different planets. A man weighing 12 stone on the earth would weigh two tons on the sun,

28 stone on Jupiter, 14 stone on Saturn, 10 stone on Venus, Neptune, and Uranus, 5 on Mercury and Mars, 2 on the moon, and a few ounces on an average asteroid.

The mean density of a planet signifies the density taken as a whole. Thus, the rocks on the earth's surface are, on the average, about two and a half times heavier than equal bulks of water; they increase in density right down to the earth's centre, where the materials must weigh nine or ten times more than equal bulks of water, and the average from the surface to the centre is five and a half. Instead of expressing the mean densities numerically, substances having different heavinesses are here given, as this affords a better means of grasping the actual facts. Mercury has a mean density equal to that of zinc, that is, the planet weighs the same as a globe of zinc of the same size. The density of the earth is equal to that of arsenic or one-half that of lead, of Venus to iron pyrites, of Mars to ruby, of the moon to flint-glass, of Jupiter and the sun to anthracite coal or dry sand; Uranus has about the density of amber, Neptune of boxwood, and Saturn of walnut-wood.

The planets have many common characteristics. They all travel round the sun in nearly the same plane, and if we could view our system from the pole star, the direction of motion would be seen to be opposite to that in which the hands of a clock move. Each planet waltzes along its orbit, the direction of spin being the same as that of the onward motion, and the satellites (excepting those of Uranus and Neptune) also revolve in this direction. But just as the different members of a family possess peculiarities of character and features, so do the individual planets; and with these planetary physiognomies we now intend to deal.

Mercury is a "will-o'-the-wisp" planet. He moves at the average rate of nearly thirty miles per second, that is, about

eighteen hundred times faster than an express train. It is only possible to see the planet shortly before sunrise or after sunset, and in our latitudes he is generally lost in the mists of the horizon. Near the equator, however, he is quite a conspicuous object, though always near the sun.

Viewed telescopically, Mercury is found to pass through phases like the moon. He also occasionally comes straight between the earth and the sun, and is then seen as a small black spot crossing the solar disc.

Owing to the proximity of Mercury to the sun, the light and heat received on a unit of surface is much greater than on the earth, and it varies considerably throughout the year of eighty-eight days. The sun is three million miles farther from the earth in our summer than in winter. But this is only a small fraction of the total distance, and the variation of the sun's light and heat due to this cause is noticed with difficulty. The path of Mercury is much less circular than that of the earth; indeed, it is so strongly elliptical that in one part of the orbit the planet is fourteen million miles nearer the sun than when at the opposite point. On this account, the intensity of solar radiation on the planet must change enormously during a revolution. If Mercury has a dense atmosphere, the blaze of sunlight must be softened in traversing it, as it is with us, but the evidence so far obtained indicates that the envelope is not so dense as that which surrounds the earth.

No conspicuous markings are visible upon the surface of Mercury, so the character of the planet cannot be read with any degree of certainty. By observing the movements of spots upon the face of a planet, the time of rotation is obtained, as in the case of the sun. The indistinctness of the markings on Mercury renders the determination of

his rotation period difficult. In 1889, a well-known Italian observer, Schiaparelli, announced that Mercury has always the same hemisphere turned towards the sun, like the moon to the earth, in which case both rotation and revolution are accomplished in eighty-eight days. Other astronomers claim that the planet rotates in about twenty-four hours, and the question is still *sub judice*.

That beautiful gem of the sky—the planet Venus—has attracted the attention of all. When visible near Christmas time, this peerless planet has been apostrophised as the "Star of Bethlehem" by many people, though there is no reason to believe that this was the object seen by the wise men of the East.

Like Mercury and the moon, Venus is seen differently illuminated at different times, according as we view the bright surface from different aspects. Galileo was the first observer of these changes, and he notified the discovery in an anagram to Kepler, which read,

"*Haec immatura a mi jam frustra liqunter.*"

These letters, when reduced to their proper order, form the sentence,

"*Cynthiæ figuras æmulatur mater amorum.*"

"*The mother of the Loves rivals the phases of Cynthia.*"

That is,

"*Venus imitates the phases of the moon.*"

We cannot resist giving an extract from the letter in which Galileo gives Kepler an account of his observations, again using Mr. Carlos' translation. "You must know," wrote the originator of physical astronomy, "that about three months ago, when the star of Venus could be seen, I began to look at it through a telescope with great attention, so that I might grasp with my physical senses an idea which I was entertaining as certain. At first, then, you

must know the planet Venus appeared of a perfectly circular form, accurately so, and bounded by a distinct edge, but very small; this figure Venus kept until it began to approach its greatest distance from the sun, and, meanwhile, the apparent size of its orb kept on increasing. From that time it began to lose its roundness on the eastern side, which was turned away from the sun, and in a few days it contracted its visible portion into an exact semicircle; that figure lasted without the smallest alteration until it began to turn towards the sun, when it leaves the tangent drawn to its epicycle. At this time it loses the semicircular form more and more, and keeps on diminishing that figure until its conjunction, when it will wane to a very thin crescent. After completing its passage past the sun it will appear to us, at its appearance as a morning star, as only sickle-shaped, turning a very thin crescent away from the sun; afterwards the crescent will fill up more and more until the planet reaches its greatest distance from the sun, in which position it will appear semicircular, and that figure will last for many days without appreciable variation. Then by degrees, from being semicircular it will change to a full orb, and will keep that perfectly circular figure for several months; but at this instant the diameter of the orb of Venus is about five times as large as that which it showed at its first appearance as an evening star."

"From the observation of these wonderful phenomena we are supplied with a determination most conclusive, and appealing to the evidence of our senses, of two very important problems, which up to this day were discussed by the greatest intellects with different conclusions. One is that the planets are bodies not self-luminous (if we may entertain the same views about Mercury as we do about Venus). The second is that we are absolutely compelled to

hat Venus (and Mercury also) revolve round the sun, o also all the rest of the planets. A truth believed, ed, by the Pythagorean school, by Copernicus, and by ler, but never proved by the evidence of our senses, as now proved in the case of Venus and Mercury."

follows from these facts that Venus must sometimes e between the earth and the sun, and like Mercury be projected upon the solar disc as a dark spot. These nsits of Venus" have been observed, and are important use they furnish a means of determining the distance ie sun from the earth.

enus is so gloriously bright that the blemishes on her can hardly be distinguished. White patches have been by some observers round what are supposed to be the et's poles, and it is possible that they are regions of ice snow such as exist round the earth's poles. A number usky markings have also been detected.

he rotation period is still a moot point. Until 1889 is said to be about twenty-four hours, but Schiaparelli questioned the observations which assign this time of to the planet. His scrutiny of the features of Venus led to the conclusion that the rotation takes place in days, this being also the period of revolution round the According to this, portions of the surface of Venus l Mercury also) are never exposed to sunlight. At ent, however, the balance of evidence favours the old od of about twenty-four hours.

here is no doubt that Venus has an atmosphere. The ring of light seen round the planet, just previous to a sit, is clear evidence of its existence. The atmosphere probably twice as dense as our own. The spectroscope ws that one of its constituents is water—vapour, as, in. d, it also does in the case of Mercury.

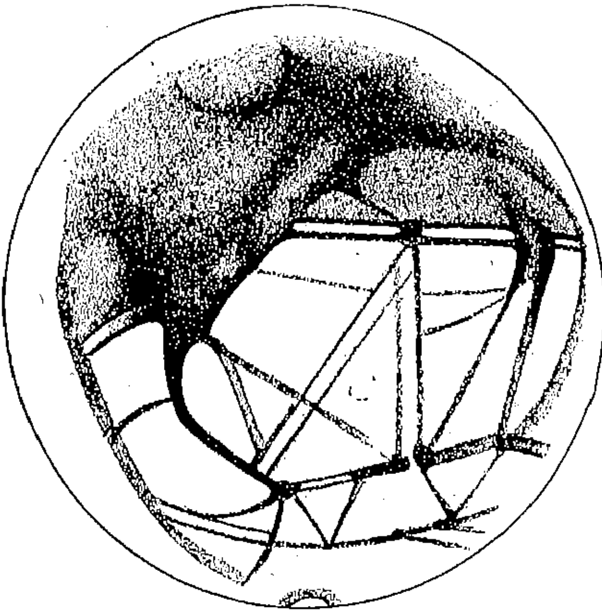
Neither Mercury nor Venus commands the attention nor directs the motions of a satellite.

An "opposition of Mars" occurred in August, 1892, and an unusual amount of interest was taken in it by the general public. When a superior planet, that is, a planet with its orbit outside the earth's orbit, is on the same side of the sun as the earth, and the three bodies are exactly in a line, it is due south at midnight, and is said to be in opposition. Now, planetary orbits are not concentric; if they were, the distance of a planet at an opposition would always be the same. Mars deviates considerably from this uniformity. If opposition occurs when he is at his greatest distance from the sun, the span of space between him and the earth amounts to more than sixty millions of miles; if, however, he is at his nearest approach when the earth comes between him and the sun, the distance from us to our ruddy brother may only be thirty-five million miles. When the latter conditions are approached the opposition is favourable, for astronomers have then the best opportunity of studying the planet. A favourable opposition occurred in August, 1892, and another will happen in 1894.

Venus approaches the earth closer than any other planet, but, as has been remarked, the markings are very faint and indistinct, owing to the dense atmosphere which enshrouds her. Mars is the next planet which approaches us within a reasonable distance, and he does so without the disadvantages which accrue to an inferior planet like Mercury or Venus. The result is that the features of the God of War have been delineated over and over again. The "scars and patches" on the face of Mars are of three kinds. Areas of a reddish shade predominate and are supposed to represent land surfaces, while regions of a greenish tinge are considered to be water. Accepting these interpretations, it

will be seen that Mars has more land than water, whereas on the earth, the reverse is the case. Round the Martian poles are white patches or ice-caps similar to those covering the polar regions of the earth. There is little doubt that these really represent masses of snow and ice; and for this

South.



North.

Fig. 17.—A view of Mars, from a drawing by Schiaparelli.

reason. When it is summer in the northern hemisphere of Mars, the northern ice-cap contracts, owing doubtless to the melting of the ice; and at the same time, the ice-covered region in the southern hemisphere increases in extent.

Conversely, during the southern summer, the southern ice-cap diminishes and the northern one increases in size.

The above-described markings are observable by an ordinary astronomer using a telescope five or six inches in diameter. Markings of a temporary character sometimes obscure parts of the planet's disc, and are regarded as clouds. The atmosphere cannot be anything like as dense as the earth's. In 1877, Schiaparelli, one of the most perspicuous observers, detected a number of straight streaks crossing the land surface of Mars in all directions, and sometimes for thousands of miles. The streaks have received the unfortunate appellation of "canals," and this, of course, suggests that they have been formed artificially. "Channels" is a much more appropriate name. The astronomical world was again startled by Schiaparelli announcing that he had seen some of the channels double. More than one observer has stoutly denied the existence of such markings as those mapped by the Milan astronomer. But on the whole, the usual and photographic observations made during the opposition of last year go to confirm Schiaparelli's work. No one has mapped anything like the details given by this astronomer, but the existence, and even the doubling, of certain channels has been substantiated. The markings on Mars are permanent and definite, therefore the period of rotation can be accurately determined. It is found to be 24 hours, 37 minutes, 22 seconds. The Martian day is thus only slightly longer than our own. By observing the paths pursued by the spots, the equator of Mars is found to be inclined to the plane of revolution, which is only two degrees more than the inclination of the earth's equator to the plane of the ecliptic. For this reason, the seasons on Mars are probably very similar to those of the earth.

Mars has two satellites, first mentioned by Dean Swift, in

"Gulliver's Travels," published in 1726. When describing the works of the astronomers on the island of Laputa, Gulliver is made to say, "'They have likewise discovered two lesser stars or satellites, which revolve round Mars, whereof the innermost is distant from the centre of the primary planet exactly three of its diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and a half." By a most remarkable coincidence, Swift not only guessed the number of the satellites correctly, but in causing one to move round the primary in less time than the planet itself rotates, he prophesied what would be deemed impossible at the present time if it were not proven by actual facts. Professor Hall discovered the two satellites of Mars in 1877, using the Washington telescope, having an object-glass, twenty-six inches in diameter. They are two of the faintest bodies in our system, and can only be seen by acute observers with large telescopes. Phobos and Deimos are the names by which the satellites are known. Phobos is less than four thousand miles from the surface of Mars, and makes more than three revolutions while the planet rotates once; Deimos is about three times farther removed from the surface, and takes thirty hours to perform a revolution.

The distances of the planets from the sun are connected by a simple relation. If we write the series of numbers 0, 3, 6, 12, 24, 48, 96 (every number except the second being double that preceding it), and add 4 to each, the series 4, 7, 10, 16, 28, 52, 100, is obtained. For an explained reason this series represents very closely the relative distances of planets from the sun. In fact, taking the distances of the earth as unity, the comparative distances of planets are, Mercury, 0·4; Venus, 0·7; Earth, 1·0; Mars, 1·5; —— , 2·8; Jupiter, 5·2; Saturn, 9·5. This

is known as Bode's Law. When the law was published it was pointed out that the actual series of planetary distances did not exactly correspond to the series arrived at numerically. No planet was known to revolve round the sun between Mars and Jupiter, so the number 28 was not represented in actuality. All the other numbers fit the planetary distances so nicely that astronomers at length concluded that a planet must exist to fill the gap in the series, and it only wanted discovering. A band of observers, therefore, decided to search for the unknown body. But before the work had well begun, on the first night of this century, Piazzi, of Palermo, discovered a new planet, and named it Ceres. Further observations enabled the path of the new body to be calculated, and the distance from the sun was found to be very nearly 2·8 times the earth's distance. The vacancy would therefore seem to be filled, though by a body far smaller than any of the other members of our system. But a year later another small planet was discovered by Olbers, and named Pallas, its distance being about the same as that of Ceres. In 1804 and 1807, two more were "picked up" as they strayed along the ecliptic, and named Juno and Vesta. Encke discovered the next in 1845. Since then the list of "minor planets" or "asteroids" has been steadily growing, and the cry is, "Still they come." The number now known is 370, as many as twenty-seven having been discovered in 1892.

Little is known about the asteroids, except that they are very small. The largest, Vesta, is just visible to the naked eye, and has a diameter of less than three hundred miles, and Ceres, Pallas, and Juno, are probably about half this size. The rest are extremely small, and quite invisible except in moderate-sized telescopes.

The simplest theory of the origin of the asteroids is that

they are parts of an exploded planet. For reasons into which we cannot now enter, this theory is improbable. A better one is that the bodies represent the materials which would have formed a single planet had it not been "spoiled in the making" by some disturbing influence.

Jupiter, the giant planet, now claims our attention. With the exception of the minor planets, the bodies so far described are more or less like the earth; they are therefore termed "terrestrial" planets. From Jupiter outwards, however, we deal with quite a different class of bodies, all much larger than the terrestrial planets, and all less dense.

On the 7th day of January, 1610, Galileo discovered that Jupiter had a retinue of four satellites, which were to him what the moon is to the earth. "In this circumstance" argued he, "we have a noteable and splendid argument to remove the scruples of those who can tolerate the revolution of the planets round the sun in the Copernican system, yet are so disturbed by the motion of our moon round the earth, while both accomplish an orbit of a year's length about the sun, that they consider that this theory of the constitution of the universe must be upset as impossible; for now we have not one planet only revolving about another, while both traverse a vast orbit about the sun, but

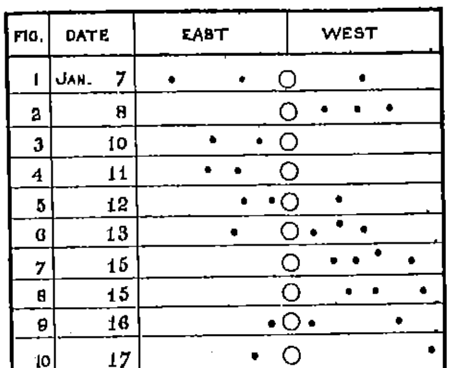


Fig. 18.—Galileo's observations of the positions of Jupiter's satellites with respect to the planet from Jan. 7th to Jan. 17th, 1610.

our sense of sight presents to us four satellites circling about Jupiter like the moon about the earth, while the whole system travels over a mighty orbit about the sun in the space of twelve years."

In 1892, nearly 283 years after Galileo's observations, Prof. Barnard discovered a fifth body revolving round Jupiter at a less distance than the nearest of the other satellites. The instrument, by means of which the discovery was made, was the 36-inch of the Lick Observatory. The new body is so near to Jupiter that it is almost smothered in the glare from his disc, and is therefore extremely difficult to see.

Jupiter is covered with markings, the most conspicuous of which are dark bands running parallel to the planet's equator, and known as "belts." Other spots and markings of a variety of tint are distributed over the surface, and make the planet a beautiful object in the telescope.

Jupiter rotates once in about ten hours, that is, makes nearly two and a half turns in one of our days. A consequence of this extremely rapid rate of spin is a considerable polar depression. The period is not determined, however, with such exactness as obtains to Mars, the reason being that the spots are not permanent features on a solid surface, but masses of cloud and vapour and breaks in them, many of which rapidly change in character. In 1878, a large "red spot" became conspicuous in Jupiter's southern hemisphere, and is still to be seen on the planet. What the spot exactly is no one can definitely say. Some observers consider that it represents a part of the planet's solid surface seen through a break in the clouds, but the prevailing opinion is that it is a mass of vapour. If the former idea were correct, all the coppery-coloured tints are probably more or less solid surfaces, and the greyish tones may be

water, the changes of tint being produced by variations in the Jovian atmosphere. There is no doubt whatever that this atmosphere exists, and contains a large amount of vapour, which is condensed into clouds like those of the earth. Of "mighty rushing winds" there is also clear evidence.

At the distance of Jupiter, solar radiation is twenty-seven times less intense than at the earth's distance. This amount

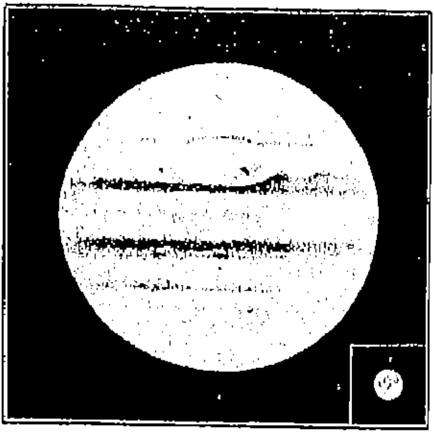


Fig. 19.—Inverted telescopic view of Jupiter, from a drawing by Professor Keeler. The small disc in the bottom right-hand corner shows the comparative size of the earth.

is too small to produce the rapid and frequent changes which are observed in the planet's appearance, hence it is inferred that it possesses a large amount of original heat, though it is not to any appreciable extent incandescent. The low mean density of the planet, and the rapidity with which it rotates, gives support to this idea.

As to the physical condition of Jupiter we can only

speculate. A small solid nucleus may be surrounded by a very deep atmosphere, or, and this is more likely, a semi-fluid globe may be enveloped in dense clouds and vapour. It is certain that the changes observed are chiefly of an atmospheric character, and that some markings are below others, but "nobody knows" whether the surface has been seen or not; indeed, it is doubtful whether any real surface exists at all.

Proceeding from the sun, Saturn is the next planet encountered. To the naked eye this object at its best appears only like an ordinary star, but the telescope has revealed a fact which makes it one of the most interesting in the heavens, and by far the most remarkable member of our system. When Galileo first observed Saturn he thought he could distinguish two small companions almost touching the surface of the planet, and made the announcement, "I have observed the most distant of the planets to have a triple form." As time went on the two attendants became smaller and smaller, and finally disappeared altogether. This worried the astronomer very considerably, for if he were mistaken on this point, all the observations he had made must be open to doubt. He pathetically remarks, "I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken, have greatly confounded me." But Galileo's eyes had not deceived him. After a time what was again supposed to be two small globes were seen to hold the planet between them. It was not until nearly half a century after Galileo's observation that the true nature of these objects was revealed. Huyghens then showed that Saturn was surrounded by a ring-system. In the words of his announcement, "The planet is surrounded by a slender flat ring

everywhere distinct from its surface, and inclined to the ecliptic." Cassini afterwards found that a dark line could be seen round the flat of the ring. This is not merely a marking but a separation between two concentric rings. Two hundred years later, in 1850, Professor Bond discovered a third ring nearer the planet than the others, and much more difficult to see. This is known as the "crape-ring," a happy term which expresses the fine texture observed.

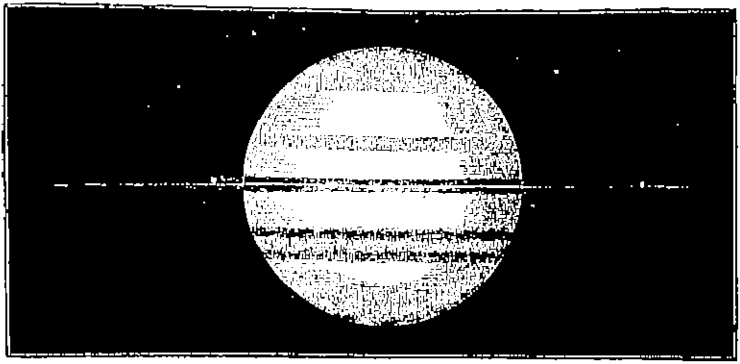


Fig. 20.—Saturn in 1861, from a drawing by Wray. The two small bright spots are two of Saturn's satellites.

Saturn travels round the sun with his flat rings inclined about twenty-eight degrees to the plane of the earth's orbit. The result is that we sometimes see the northern side of the ring and sometimes the southern. Once in about fifteen years the plane of the rings passes through the sun, and only the edge facing the sun is then lit up. It was owing to these changes in the amount of illuminated surface visible that Galileo's "globes" disappeared, for they were not globes at all but the rings. Good telescopes then show what looks like two spikes, one on either side of the planet. The spikes are seen to be irregular in thickness, thus show-

ing that the rings are not uniform sheets. To understand the cause of the phases through which the rings pass, the student is recommended to place a lamp upon a table, and walk round it while a friend carries round a plate inclined to the level of the table, and always in the same direction. According to the relative positions of the student and his friend, the plate is sometimes viewed edgeways, sometimes squarely, and sometimes obliquely, just as is the case with Saturn.

The outer ring of Saturn has a diameter of about 170,000 miles, and the average thickness is less than 100 miles. Hence, even if the bright rings were solid concentric sheets of the strongest material with which we are acquainted, their vast extent and insignificant thickness would make them very flimsy, and comparable to a sheet of writing-paper round a large globe. But solid rings could not exist round a globe of Saturn's dimensions, and a liquid ring would soon be broken up. The only form in which mathematicians will allow the rings to exist is by being composed of innumerable particles revolving round the planet like the asteroids round the sun. It can be proved that each member of a swarm of solid particles would be caused to revolve round Saturn in the plane of the equator, just as the rings are observed to do.

Saturn is distinguished in other ways in addition to his marvellous rings. He has the least mean density of any of the planets; indeed, he only weighs as much as a globe of walnut-wood of the same size, and would therefore actually float in water. The polar flattening is greater than any other planet. This follows as a consequence of the low density and the high velocity of rotation (about 10¼ hours). Cloud-belts similar to the belts of Jupiter are seen, and the markings undergo changes, but not in the "fast and

furious" manner observed on Jupiter. Another fact which singles Saturn out from the other members of the sun's family is that he has the largest number of attendants, namely, eight.

We have come to the end of the planets known to the ancients. The date of their discovery is anterior to any times of which we have any historic record. The first planet added to the list was found by Sir William Herschel in 1781. It is just visible to the naked eye at times, but not bright enough to attract any attention. Herschel was "searching the skies" when a strange-looking star attracted his attention, and after watching it for some time under different conditions, he decided that it was a comet. An announcement of the discovery was made, and other astronomers observed the object. It was soon found, however, that the body did not move in a cometary path, and the conviction was gradually forced upon astronomers that it was a new planet. Such a thing had never been heard of before, for every astronomer had looked upon Mercury and Saturn as representing the Alpha and the Omega of the solar system. The name of Uranus was given to the planet, and when its orbit had been properly calculated, the mean distance from the sun was found to be nineteen times the earth's distance, which agreed very well with the number given by Bode's law.

Very little is definitely known about Uranus. His mean density is about the same as the sun and Jupiter, that is, rather more than the density of water. The physical condition is probably similar to that of Jupiter and Saturn, and there is clear evidence that the planet possesses inherent or original heat. Owing to the indistinctness of the markings on the planet's surface, the period of rotation has not been obtained. Faint belts have been glimpsed by some ob-

servers, and from their direction the position of the equator has been estimated. The poles must, of course, be at right angles to this position: But observations of polar compression locate the poles in quite a different position to that indicated by the cloud-belts. Both cannot be right, and since the markings are excessively faint, it is probable that the direction deduced from measures of the flattening is correct.

Uranus has four satellites revolving round him in nearly circular orbits, and probably in the plane of the equator. The plane of the orbits is inclined about eighty degrees to the ecliptic, hence the satellites are seen almost at right angles to the ecliptic, instead of lying nearly in it, like those of the planets already described. More remarkable still is the fact that the direction in which the satellites move is the reverse of that possessed by all the planets and by the satellites to which reference has been made.

Uranus had been assigned a place and name, and he was expected to behave like a respectable planet. Calculations were made on the assumption that he would do so, and the places he ought to occupy at particular dates were predicted. But astronomers were doomed to disappointment. Uranus was never to be found in exactly the proper place; he was misguided by some unknown influence.

In 1845, the deviation from the path of rectitude had become so great that astronomers all agreed that something must be done to find the body which had Uranus under its control. Science, and especially the science of astronomy, is nothing, if not exact. The amount by which the real position of Uranus differed from the calculated position would be considered by most people as far too small to make a fuss about. A halfpenny viewed at a distance of fifty feet would cover the difference between the

two points. Two astronomers set to work to calculate the position of the disturbing body. One was a young and then unknown Englishman named Adams; the other was a brilliant French mathematician, Leverrier. Each worker independently found where the controlling planet ought to be, and each communicated his results to an observer. Adams laboured under the double misfortune of being young and of having no *locus standi* in the astronomical world. The result was that his calculations were hardly regarded seriously. Leverrier finished his investigation after Adams, and sent to Dr. Galle, telling him where to look for the body which had been felt, but not seen. On the very night (September 23rd, 1846), and in less than half an hour after the search was commenced, the new planet was found close to the predicted place.

This planet is known by the name of Neptune. Unlike the rest of the planets, its distance from the sun does not conform to Bode's law. At 30 times the earth's distance, Neptune journeys round the sun, whereas Bode's series previously mentioned (p. 85) would make the number 38.

Next to Saturn, Neptune is the least dense of the planets. The period of rotation cannot be determined, owing to the absence of visible markings. In all probability the planet possesses inherent heat, and is in a similar vaporous condition to Jupiter, Saturn, and Uranus. One satellite has been found revolving round Neptune, its distance being about the same as that of Mars from the earth. The orbit is inclined considerably to the ecliptic, and in it the satellite moves in the same retrograde fashion as the Uranian satellites.

Such are the general characters of the members of the system ruled over by the sun.

The question of the habitability of the planets and

satellites is full of interest, but, unfortunately, we have no evidence upon the matter. It is hardly possible to conceive of life upon the sun, and certainly not life as we know it. Where iron and other metals are dissipated into vapour as easily as water upon the earth, terrestrial organisms could not exist. A lunar residence does not offer many advantages. Those who long for a quiet life would attain their desire upon our satellite, for, in the absence of an atmosphere no sound could be heard. But the climate is far from being equable, owing to the considerable range of temperature. Someone has fantastically suggested that the inhabitants of the moon do not live upon the surface, but have burrowed towards the centre where warmer regions prevail. It is, of course, not impossible that a race should be created specially fitted to live upon the moon. To obtain information upon this point, it was proposed some years ago to erect immense triangles or circles upon plains or desert places of the earth. If there are lunarians, and they possess telescopes, our geometrical figures might be seen and replied to by setting up similar figures upon their own globe. Venus and Mars offer residences more congenial to us than the sun or moon. The former planet has an atmosphere rather denser than that of the earth, and there is very little difference between the sizes of the two globes. Though the intensity of solar radiations at Venus is about twice that received by the earth, the dense atmosphere would modify it very considerably. Indeed, so far as one can tell, many, if not most parts of Venus could be inhabited by human beings.

During the opposition of Mars in 1892, a large amount of interest was manifested in the question as to whether the planet is peopled or not. In many respects Mars is very similar to the earth. His day is about the same length,

and the seasonal differences are alike. We see markings supposed to be water, and others interpreted as land; hence it seems as if our ruddy brother offered "desirable residences" to terrestrial beings. On the other hand, though Mars has an atmosphere in which water vapour is present, it is nothing like so dense as that of the earth. An astronomer on Mars would most probably be unable to see any of the features on the surface of the earth, owing to the vaporous envelope which surrounds us, whereas it is only rarely that clouds obscure any portion of the Martian surface. Various projects of signalling to Mars have been suggested, but it is not likely that any of them will be carried into effect for a number of years. If there are Martian people they must watch our earth with great interest, and probably point to it as the abode of love and peace, for it must be a beautiful object in their sky. When we see Mars at his best, however, the earth is invisible to the Martians. With the exception of Mercury, none of the remaining planets are in what we consider a fit condition of habitation, for each very probably consists of dense vapours surrounding a semi-fluid nucleus, and devoid of a crust like that of the earth.

THE PLANETS.

The values in this and the following table are chiefly those given in Young's "General Astronomy."

	Mercury.	Venus.	The Earth.	Mars.	Jupiter.	Saturn.	Uranus.	Neptune.
Greatest distance from the sun in millions of miles, ...	43·5	67·5	94·5	154·5	504·0	986·0	1,880	2,825
Least distance in millions of miles	28·5	66·5	91·3	128·5	462·0	786·0	1,720	2,775
Mean " " "	36·0	67·0	92·9	141·5	483·0	886·0	1,800	2,800
Greatest distance from the earth, in millions of miles, ...	137·0	162·0	...	249·0	598·5	1080·0	1,974	2,919
Least distance in millions of miles,	47·8	23·8	...	36·0	367·5	692·0	1,626	2,683
Length of revolution period in years	0·24	0·62	1·00	1·88	11·86	29·46	84·02	164·78
" synodic revolution in days,	116	584	...	780	399	378	370	367
" rotation period, ...	88 days	24 hours	23h 56m 4s	24h 37m 23s	9h 55m	10h 14m	unknown	unknown
Mean diameter in miles, ...	3,030	7,700	7,918	4,230	86,500	73,800	31,900	34,800
Mass, compared with the sun, ...	doubtful	$\frac{1}{425000}$	$\frac{1}{331100}$	$\frac{1}{3093500}$	$\frac{1}{1047}$	$\frac{1}{[illegible]}$	$\frac{1}{[illegible]}$	$\frac{1}{[illegible]}$
" " " earth,	$\frac{1}{15}$	$\frac{4}{5}$	1	$\frac{1}{11}$	310	93	14	17
Volume, " "	0·056	0·920	1·000	0·152	1,309	770	65	85
Mean density " "	2·23	0·86	1	0·72	0·24	0·13	0·22	0·20
" " water,	6·85	4·81	5·66	4·01	1·38	0·75	1·28	1·15
Force of gravity at the equator,	0·85	0·83	1·00	0·38	2·65	1·18	0·91	0·88

THE SATELLITES.

Name of Satellite.	Name of Primary.	Distance from Primary.	Period of Revolution.				Diameter.
		Miles.	Days.	Hrs.	Min.	Sec.	Miles.
Moon	Earth	238,840	27	7	43	11·5	2,163
Phobos	Mars	5,850	0	7	39	15·1	7
Deimos	„	14,050	1	6	17	54	5
Not named ...	Jupiter	112,500	0	11	58	0	100
Jo	„	261,000	1	18	27	33·5	2,500
Europa	„	415,000	3	13	13	42·1	2,100
Ganymede	„	664,000	7	3	42	33·4	3,550
Callisto	„	1,167,000	16	16	32	11·2	2,960
Mimas	Saturn	117,000	0	22	37	5·7	600
Enceladus	„	157,000	1	8	53	6·9	800
Tithys	„	186,000	1	21	18	25·6	1,100
Dione	„	238,000	2	17	41	9·3	1,200
Rhea	„	332,0.0	4	12	25	11·6	1,500
Titan	„	771,000	15	22	41	23·2	3,500
Hyperion	„	934,000	21	6	39	27	500
Iapetus	„	2,225,000	79	7	54	17·1	2,500
Ariel	Uranus	120,000	2	12	29	21·1	500
Umbriel	„	167,000	4	3	27	37·2	400
Titania	„	273,000	8	16	56	29·5	1,000
Oberon	„	365,000	13	11	7	6·4	800
Not named ...	Neptune	225,000	5	21	2	44·2	2,000

CHAPTER VI.

COMETS AND SHOOTING STARS.

THE sun and moon, and planets, are what may be termed well-behaved celestial bodies. They do nothing abruptly. The sun can be confidently expected to rise to-morrow morning and present his usual appearance; we have faith that the moon will wax and wane in the future as she has done in the past, and that the planets will be found in their appointed places for many years to come. The regularity of these returns was observed long before the laws which govern them had been worked out, and men saw no cause to fear the bodies which conducted themselves in this "highly respectable" manner. Comets, on the other hand, have such rapid and apparently erratic motions that they have at all times struck terror into the hearts of people. They appear in the sky without harbingers of any kind, "shake their horrid hair" over the earth as they increase in brilliancy and magnitude, and apparently threaten the world with evil. Even in this enlightened century, great comets are viewed with feelings of awe and anxiety. No wonder, then, that in earlier days the appearance of a comet was regarded as a manifestation of divine wrath, and in the object itself heated imaginations saw forms of javelins and swords, dragons and demons, and burning flames.

Many of the six or seven hundred comets recorded in historic time are associated by ancient chroniclers with terrestrial affairs. Shortly after the murder of Cæsar, a comet was seen, which the Romans imagined represented him deified. The immortal bard expresses the connection between the two events in the lines:—

> "When beggars die, there are no comets seen;
> The heavens themselves blaze forth the death of princes."

Josephus records that a comet hung over Jerusalem while the city was being besieged by Titus, and "in it," says Pliny, "one may see the image of God in human form." An interesting comet also appeared in 1066. It was regarded as a presage of the conquest of England by William of Normandy, and is figured in the Bayeaux tapestry.

A remarkable comet appeared in 1680, that is, just after the discovery of the law of gravitation. Newton had found that the motions of the known members of the solar system were completely accounted for by this universal law of attraction. The planets travel in elliptic orbits round the sun. True, the ellipses are of comparatively small eccentricity, that is, they only differ slightly from circles, but Newton proved that this form of orbit followed as a necessary consequence of the law of gravitation. He argued that since the law can explain one kind of elliptical motion, it ought to be applicable to ellipses of any eccentricity. A word of explanation is here necessary.

A method of drawing an ellipse is illustrated in the accompanying figure. When the two pins are close together, the figure traced out by the pencil held in the loop of thread is hardly distinguishable from a circle. By increasing the

distance between the pins, ellipses of a more and more elongated form are produced, and if it were possible to place one of the pins at an infinite distance from the other, the beautiful geometrical figure known as parabola could be drawn. Hence, there is every gradation between an ellipse in which the two foci very nearly coincide, and a parabola in which the foci are separated by an infinite distance. We know that a body moving in an elliptical path traverses the track over and over again. A body moving in a parabolic orbit round the sun must behave very differently. It comes from outer space, swings round the sun in the focus of the curve, and then goes off never to return, for it can never get

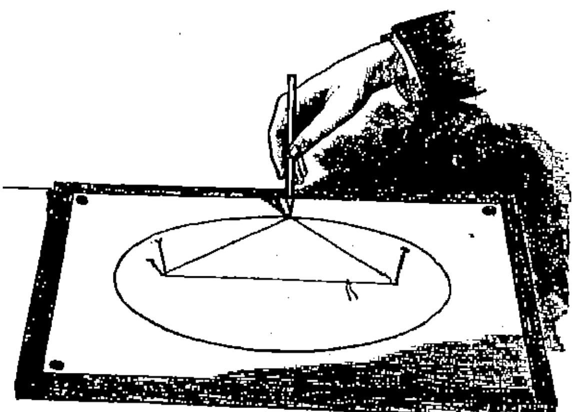


Fig. 21—The Construction of an Ellipse.

round the other focus. Reasoning in this manner, Newton was led to the idea that comets moved in parabolic curves, and he selected the comet of 1680 to test its validity. Observations of the positions occupied by the comet at different dates during its appearance furnished the materials

from which the form of the path could be determined. When the calculations were completed, the path was found to be a parabola, and the line connecting the comet to the sun described equal areas in equal times, just as the most dignified planet. The apparently adventitious motions of comets were thus found to be reducible to law and order, and the decline of the superstitious dread in which the objects had been held began with Newton's discovery. Since that day two hundred or more comets have been found to move in parabolic paths. Whence they come and whither they go no man knows. In far-off regions of space the sun's influence is felt. A comet is beckoned by the authoritative call and obeys. It begins the journey to our system, moving tardily at first, but slowly and surely increasing its speed. A year, ten years, or it may be a hundred years, pass before the traveller comes in sight. With terrible rapidity it shoots round the mighty globe to which it has come to pay obeisance, and then away, away, away into the darkness of infinite space it goes, and is lost to us for ever. To use the simile employed by one of King Edwin's men to the life of a man, "It is as a sparrow's flight through the hall when you are sitting at meat in winter-tide, with the warm fire lighted on the hearth, but the icy rain storm without. The sparrow flies in at one door, and tarries for a moment in the light and heat of the hearth fire, and then flying forth from the other vanishes into the wintry darkness whence it came."

But there are comets which call upon us periodically as well as those which pay us single flying visits. This fact was discovered by the English astronomer, Halley, in 1682. An examination of old records led him to conclude that the same comet had appeared after a certain interval of time; that, in fact, there were comets with elliptical, as well

as comets with parabolic orbits. He showed that a comet of 1682 and one of 1607 were identical, and a relation appeared to exist between them and a comet of 1531. From this Halley inferred that the three objects were one and the same body travelling round the sun in a period of about seventy-six years. If that were so, the comet should return in 1759, and the astronomer confidently predicted its reappearance. The prophecy was fulfilled. Halley's comet made the long-expected call, and by so doing showed that its motions were controlled by the same "secret, strong, attractive force" as that which binds the planets. The only difference, then, between the path of a comet of this character and that of a planet is in the form of the ellipse. The comet's ellipse is very elongated—the foci are separated by a considerable distance—whereas in a planetary ellipse the foci are comparatively near together. In each case, however, the sun is situated in a focus of the ellipse, and from this it follows that the comet's greatest and least distances from the sun are enormously different. Mercury has the most eccentric orbit of the planets, the difference between his greatest and least distances amounting to 15 million miles. Halley's comet is 56 million miles distant from the sun at its point of nearest approach, and 3,200 million miles away when at the opposite end of its orbit. The difference between the greatest and least distances is thus 3,144 million miles. By an examination of old records, Dr. Hind was able to trace Halley's comet back to eleven years before the commencement of our era. The comet of 1066, which Duke William interpreted as a sign of the coming downfall of Saxon England, was the same body as that which Halley observed and investigated. It will return again in 1911.

In 1819 a comet was found by Encke to move in an ellip-

tical orbit, that is, in a closed curve. Halley's comet comes like an illustrious foreigner, in pomp and splendour, but its visits are "few and far between." Encke's comet is modest both in its tour and appearance. It makes a call upon the sun once in three and one-quarter years, but without pretentious display. Indeed, it is usually invisible to the naked eye, even at its brightest.

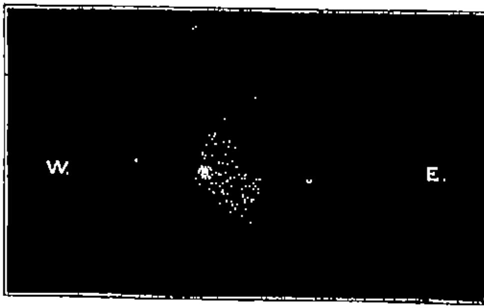


Fig. 22.—Encke's Comet in 1891.

The comet is 32 million miles from the sun at the point of nearest approach, and has a distance of 387 million miles when most removed from our luminary. Jupiter's distance is 483 millions of miles, so the comet's orbit is inside that of the giant planet.

An interesting fact connected with Encke's comet is that its period is gradually decreasing, being three days less at the present time than it was when the periodicity was discovered. There must be a reason for this, and the theory suggested by Encke is that the comet has to pass through something round the sun—probably an extension of the solar atmosphere—which tends to retard its motion. This resistance causes the comet to describe a smaller path. The period of revolution is therefore diminished, and we thus get the paradoxical result of a body appearing to move faster in consequence of something trying to stop it.

Comets admit of being classified according to their orbits,

First there are those which move in parabolas, and rush away after taking a rapid glance at our part of the universe. The majority of comets travel in curves of this kind. Next we have the comets which run down and say, "How d'ye do" to the sun once in a few centuries—comets of long period. Forty comets, more or less, belong to this class. In addition, there are something like twenty comets which move round the sun once in less than ten years, and are known as comets of short period.

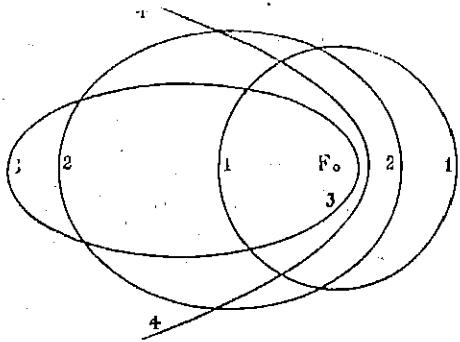


Fig. 23.—F. is a focus of each of the figures; 1, 1, a circle; 2, 2, an ellipse; 3, 3, an ellipse of large eccentricity; 4, 4, a parabola.

Parabolic comets behave like excursionists to the solar system. They come out of all parts of space, and some travel round the sun in a right-handed fashion, while others have a left-handed direction of motion, like the planets. With a few exceptions, all the comets having elliptical orbits move in the latter direction, in this uniformity differing from the indiscriminate motions of their parabolic brethren.

There is very little doubt that all periodic comets are immigrants to the solar system from outer space, and not natives like the planets. Attracted by our little family, they swoop towards us in beautiful parabolas, but with no intention at all of staying. Occasionally, however, one of

the major planets happens to be near the line of travel as the celestial visitor hurries along it. When the two bodies are so situated that the comet is held back slightly by the attraction of the planet, the parabolic orbit becomes transformed into an elliptical one. The vagabond is thus made a prisoner, having been captured by a planet, and instead of flitting away into realms unknown, it is forced to march along a certain track and report itself periodically for the delectation of astronomers. Though, on the average, only three or four brilliant comets appear in a century, many more are observed telescopically; indeed, scarcely a year passes without half a dozen being discovered. A telescopic comet has the appearance of a small patch of mist in the sky, and cannot be distinguished from one of a large class of celestial bodies known as nebulæ. It is impossible to say from the first observation whether the object will become prominent or not. In general, a slight brightening near the centre is observed as the comet approaches the sun, "only that, and nothing more." A comet born to become famous soon distinguishes itself, however, from the commonality. The brightening near the centre becomes concentrated to a star-like nucleus, from which luminous jets are shot out towards the sun. By the time this kind of action commences, the comet is usually to be seen with the naked eye. Luminous envelopes are shed by the comet on the same side as the jets, and both jets and envelopes are driven back as if repelled by the sun, and go to form what people erroneously consider to be the characteristic of all comets, namely, the tail. The order of these changes varies somewhat, for no two comets behave exactly alike. The most remarkable circumstance is the strong repulsion of the material of which the jets and envelopes are composed to form the comet's tail. It results from this that the tail

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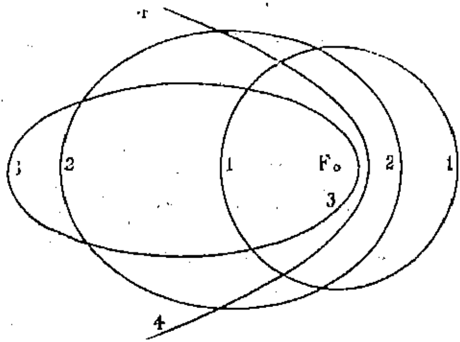

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is pointed away from the sun no matter what position the comet occupies in its orbit. When the sun is being ap-

Fig. 24.—"The tail is pointed away from the sun no matter what position the comet occupies in its orbit."

proached, the tail follows the head, but when the comet is receding, the tail goes first.

The splendid comet which appeared in 1858, and was discovered by Donati of Florence, exhibited a striking series of changes. From a small patch of nebulosity it grew until the head was a quarter of a million miles in diameter. Seven concentric envelopes were at one time seen to enfold the nucleus on the sunward side and to bend back in beautiful sweeps to form the tails. The most conspicuous tail was curved like a scimitar, and in October, 1858, it had a length of more than fifty million miles. At a short distance in front of the convex side two faint streaks were visible, extending straight out from the nucleus to even a greater distance than the tail, which was such a marked feature of the comet.

Professor Bredichin of Moscow has made a very exhaustive investigation of comets' tails and the causes which produce them. He classifies the tails into three types, namely, the straight, plume-like, and stubby. There can be little doubt that the material of the jets and envelopes are repelled by the sun to form all kinds of tails, but we can only

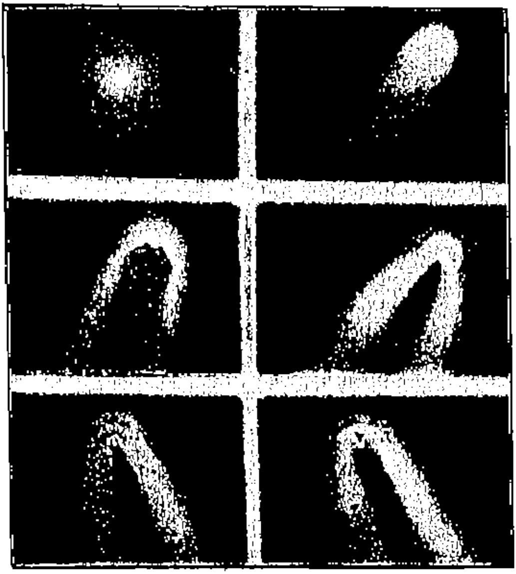


Fig. 25.—"The head of the splendid comet which appeared in 1858 exhibited a striking series of changes."

speculate as to the nature of the repelling force. Professor Bredichin's investigation has led him to conclude that the tails of comets which point straight away from the sun are composed of hydrogen. This element, among others, is emitted from the nucleus; it tends to obey the behest of gravitation and fall towards the sun, but the sun drives it

back with a force about twelve times greater than the attractive power, so away it goes into space like an arrow from a bow. The two straight streaks observed in Donati's comet probably represented the edges of a tail of this character. For the substances in the plume-like tails the repelling force is less than twice as strong as the gravitational attraction, hence they are not driven back so forcibly as the hydrogen. The vapours of hydrocarbons are probably the constituents of this type of tail. The conspicuous tail of Donati's comet is a perfect example of this form. The materials of which the short, strongly-bent, or stubby tails are composed are only repelled by a force about one-fifth as strong as the force of attraction. They possibly consist of the vapour of iron and similar heavy substances.

Many comets attain enormous dimensions. The great comet of 1811 grew until its head was more than one million miles in diameter, and its tail of one hundred million miles long had a breadth at the end of fifteen million miles. In spite of this great show, however, comets are not weighty bodies. One hundred thousand of the largest comets ever observed would not weigh as much as the earth. In 1776, a comet passed Jupiter at a distance less than his outermost satellite, without affecting the motions of the satellites in the slightest degree. The comet itself, however, paid for its daring approach to the giant planet, for its orbit was considerably altered. Since the volume or bulk of a comet is so great, and the mass of the whole object is so insignificantly small, the mean density must be less than anything of which we have any conception. Suppose we could take a comet, head, tail, and all, and put it in one pan of a balance, and we could carve out from the air which surrounds us an object of the same size to put in the other pan, we should find that our

aerial body weighed four or five thousand times more than the comet. This does not show, however, that comets are nothing but gases in a state of extreme tenuity. The head may be, and very probably is, composed of a large number of small but solid bodies; nevertheless, when the comet is taken in its entirety, the mean density is extremely low. A convincing demonstration of this spiritual texture is afforded by the fact that stars suffer no change of place or brilliancy when a comet passes in front of them. In 1861, the earth passed through the tail of a comet, and the only result noticed by the most observant was that the sky seemed tinged with a peculiar light. There is little doubt that the earth has also passed through the head of a comet. The history of this event is as follows. In 1826, Biela found that a comet he had observed revolved round the sun in a period of about six years and seven months. The comet returned in due course, and its periodic character was established. In 1845, however, the comet split into two parts, and at the next return, in 1852, the twins were again seen, but the distance between them had increased. The split must have marked the beginning of an utter disintegration, for the comet has not since been seen, though it has been carefully looked for. But this is not the whole of the story. At the end of November in 1872, and 1885, and 1892, beautiful showers of shooting stars were seen when the earth was near the place which the comet would have occupied had it lived and walked in the path allotted to it. This led to the conclusion that the earth passed through the comet on these dates, and that the shooting stars represented its fragments rendered luminous, and dissipated into vapour as they entered the earth's atmosphere.

The spectroscope shows that comets are, to a very large extent, self-luminous, and that the constituents which mani-

fest themselves in the most decided manner are carbon and its compounds. This fact is not without interest, for all animal and vegetable substances contain carbon in some form or other. It must not for a moment be supposed, however, that astronomers of the present day believe comets to be the abode of life because carbon exists in them. Comets are subjected to such extremes of temperature that life upon them would be far from pleasant. One old astronomer said that they could not be abodes of happiness, but "places of punishment for the wicked, who were alternately wheeled into regions of intolerable heat and afterwards exposed to all the regions of the most intense cold."

Prof. Lockyer has collected all the spectroscopic observations that have been made of comets and investigated them. He finds that though the characteristic spectrum of a comet is the same as that given by the blue part of a candle flame, and is therefore chiefly due to hydrocarbon gases, a number of small differences occur as a comet increases and decreases in temperature. Comets which approach very near to the sun exhibit the fact in this spectra, while those at a great distance report that their temperature is low.

Who has not been startled when looking on the sky at night by seeing a shooting-star? A point of light glances across the sky, leaving a luminous trail which hangs in the heavens for a few seconds and then disappears. To all appearances a star has fallen from its place in the celestial vault, but as a matter of fact this is not so. The word star applied to the point which sparkles and dies is a libel upon the mighty suns fervidly shining in infinite space. Shooting-stars are small particles of matter revolving round the sun like the earth. Our globe is constantly plunging into these specks of cosmic dust and attracting them towards itself.

The consequence is that they enter our atmosphere with an average velocity of thirty miles a second. A rifle bullet becomes hot in passing through the air though its velocity is far less than this. It can easily be understood, then, that a particle which enters the earth's atmosphere at the terrific speed of thirty miles a second, must become very hot by friction against it. In fact, the heat developed is sufficient to melt and vapourise the solid particle, and its dissipation in this manner produces the phenomenon of a "shooting-star."

Observations indicate that space is filled with fragments of this kind. Dr. Schmidt, observing in the clear sky of Athens, found that the average number of shooting-stars seen by one observer between twelve and one o'clock on a clear, moonless night, is fourteen. Six observers would be required to include the whole of the sky above the Athens horizon in their view, and about sixty thousand to take in all parts of our aerial envelope. Hence, the average hourly number of shooting-stars which would be seen if observers could be distributed all over the earth, is fourteen times sixty thousand, that is eighty-four thousand. In twenty-four hours, therefore, the number of particles which enter the earth's atmosphere is about twenty millions, and each is capable of producing the phenomenon of a shooting-star. In addition, there are shooting-stars too faint to be seen by the naked eye, but visible in telescopes. Including these in the estimate, we have the astonishing fact that something like 400 millions of solid particles rain down upon the earth and are consumed in the atmosphere daily. Prof. Newton, of New Haven, is the authority on these matters, and he estimates that each particle is about two hundred and fifty miles from its neighbours.

When two or more observers see the same shooting-star

from different places, and notice the length and direction of the trail, the height at which the particle commenced to be luminous and that at which it was entirely burnt up can be calculated. The average height at which luminosity commences is about seventy-six miles, and extinction occurs at a height of about fifty-four miles.

Closely allied to shooting-stars are the brilliant meteors or fire-balls occasionally seen. The difference between the two classes of bodies is very probably only one of size, for both owe this luminosity to friction against the earth's atmosphere. Fire-balls being larger portions of matter than shooting-stars, present a larger surface to the atmospheric brake, and, as a result, become luminous at a greater height above the solid ground. They are also not consumed so readily, the average height at which all the material is dissipated into vapour being thirty miles. Some

Fig. 26.—The Otumpa meteorite. From a photograph of the original in the collection of the British Museum (Natural History).

of the meteors are so large that they reach the earth's

surface before sufficient heat has been developed to drive them entirely into vapour, and with a roar they hurl themselves down, spreading consternation in the districts where they fall. These celestial missiles which fulfil their original intention of striking the ground are known as "meteorites." There are a number of well-authenticated records of such falls from heaven, though it was not until the beginning of this century that their celestial origin was believed in.

In the tenth chapter of Joshua we read, "The Lord cast down great stones from heaven," and, if this refers to a fall of meteorites, it is the earliest record of such an occurrence. Livy mentions a fall of meteorites which took place about 650 B.C. In the words of this Roman historian, "News was brought to the king and the fathers that it had rained stones on the Alban Mount. Wherefore, though it seemed scarcely credible, when men were sent to observe the portent, stones fell thickly from heaven in their sight." The fall was accompanied by a "mighty noise," which was interpreted as a manifestation of the displeasure of the gods, so a nine days' solemn festival was held. Other falls from the sky are mentioned by early writers, and many of the stones were worshipped as "holy things fallen from heaven." The oldest undoubted meteorite now in existence is suspended by a chain in the parish church of Ensisheim in Alsace. The excellent guide to the meteorites in the Natural History section of the British Museum contains the following account of the meteorite at Ensisheim, being a translated extract from a document kept in the church. "On the 19th of November, 1492, a singular miracle happened; for between eleven and twelve in the forenoon, with a loud crash of thunder and a prolonged noise heard afar off, there fell in the town of Ensisheim a stone weighing 260 pounds. It was seen by a child to strike the ground

in a field near the canton called Gisgaud, where it made a hole more than five feet deep. It was taken to the church as being a miraculous object. The noise was heard so distinctly at Lucerne, Villing, and many other places, that in each of them it was thought that some houses had fallen. King Maximilian, who was then at Ensisheim, had the stone carried to the castle; after breaking off two pieces, one for the Duke Sigismund of Austria, and the other for himself, he forbade further damage, and ordered the stone to be suspended in the parish church."

The largest mass in the collection of the British Museum weighs about three and a half tons, and was found at Cranbourne in Australia about 1854.

The chemical elements most frequently found in meteorites are, in the order of plenitude, iron, nickel, phosphorus, sulphur, carbon, oxygen, silicon, magnesium, calcium, and aluminium, while those less frequent or plentiful are, hydrogen, nitrogen, chlorine, lithium, sodium, potasium, strontium, titanium, chromium, manganese, cobalt, arsenic, antimony, tin, and copper. There are three forms in which carbon occurs on the earth, represented respectively by lamp-black, black-lead, and diamond, and each has been formed in meteorites. Usually carbon occurs in one of its compound forms, and sometimes in forms which would be taken as an indication of animal or vegetable existence if found upon the earth. The iron of meteorites usually occurs alloyed with nickel, and is never found alone. Though no new element has been discovered in meteorites, many combinations, entirely unknown in the crust of the earth, occur in them.

Meteorites are conveniently divided into three classes according to their constitution, and named respectively, "siderites," "siderolites," and "aerolites." Siderites, or

"meteoric irons," contain from eighty to ninety-five per cent. of iron alloyed with from six to ten per cent. of nickel, and are almost indistinguishable from masses of iron of terrestrial origin. Siderolites consist of large proportions of iron and stony matter; while aerolites are composed chiefly of stray matter, and are known as "meteoric stones."

There is every gradation between the fire-ball which rushes through the air and reaches the ground as a meteorite and a noiseless shooting-star, and it was concluded a century ago that the two are only varieties of one phenomenon. Both are also connected with comets, and it is now our purpose to give an account of the facts which led to the discovery of this intimacy.

Usually shooting-stars are seen one at a time, and they glance across the sky in any direction. At regular intervals, however, we see "the vaulty top of heaven, figured quite o'er with burning meteors." Shooting-stars shower down from the sky almost as abundantly as flakes of snow during a snowstorm. A circumstance which soon attracts the attention of an observer of a great shower of this description is that all the meteors appear to shoot away or radiate from a particular part of the sky, known as the "radiant" or "radiant-point." And even when showers of a less remarkable character are observed, when perhaps only one or two meteors are seen at the same instant, the streaks point backwards to a radiant. Near the radiant the meteors have very short trains, while those farther away are visible over long tracks. This is explained as an effect of perspective. When we look through a long straight gallery or tunnel, the roof, floor, and sides are seen to converge to one point, known to artists as the "vanishing-point." The radiant-point is similarly produced. The meteoritic particles are travelling in practically parallel paths when the earth plunges in

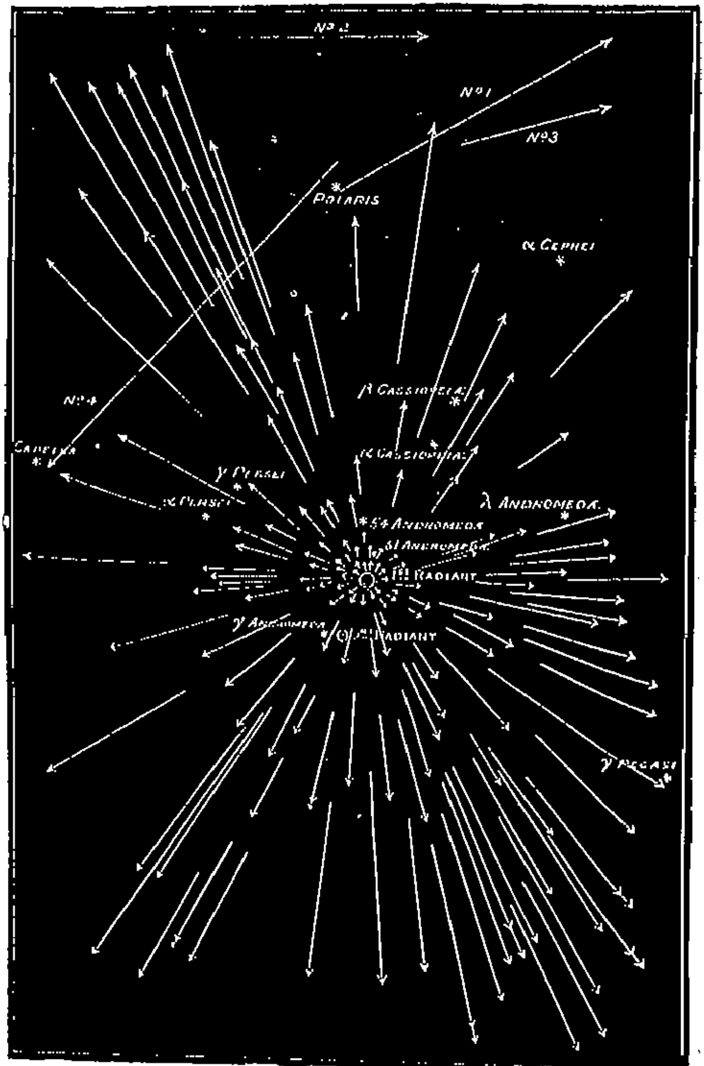


Fig. 27.—The meteors of Nov. 27th, 1872, and their "radiant-point."

among them. Owing to the brake put upon their motions, the meteors leave behind them a luminous trail of the paths they pursue, and when we look through all these parallel streaks we see them converging to a "vanishing-point" in the sky, just as the parallel walls, floor, and roof of the tunnel were observed to do. Hence the radiant marks the actual direction of motion of the meteors when the earth meets them.

Showers of shooting-stars recur periodically. Professor Newton, by looking up ancient chronicles, found that brilliant displays had been observed in the same part of the sky about the middle of November every thirty-three years. A simple illustration will make clear the cause of this periodicity. Suppose a policeman in a country district completes his extended beat in a week, going round, say a dozen small villages, in this time. Week after week the journey is made with little to relieve the monotony of it, until an unpleasant incident occurs. As he leisurely approaches The Lion hostelry one day, he is pelted with peas by a number of boys journeying home on their holidays. As the string of coaches pass him, from each he receives a tantalising shower. However, the end of the line is reached in time, and the guardian of the peace then proceeds unmolested on his way, mourning over youthful depravity. Nothing happens for thirty-three weeks, when the boys are again homeward bound. They come down the road from The Lion and assail him just as before. Thirty-three weeks later, the incident is repeated, and again after the same interval. It then dawns upon him that once in thirty-three weeks he meets a stream of boys coming down a particular road, and is greeted with a shower of peas. Now this is analogous to what occurs with the earth. Every thirty-three years, when the earth is at a particular part of

her orbit, a stream of meteoritic particles coming from the direction of The Lion constellation, happens to meet us, and the result is that we get a shower of shooting-stars as we pass through it. It is inferred from this that the stream journeys round the sun once in thirty-three years, in an orbit which crosses the orbit of the earth. When both reach the "level-crossing" together a brilliant meteor shower testifies to the encounter.

The meteors which radiate from The Lion constellation are known as Leonids. The stream of solid particles which produces them is so long that it takes about two years to cross the earth's orbit, consequently meteoric showers may occur about the middle of November two years in succession. The last display was in 1866, and the next will be in 1899. At the end of November once in thirteen years showers are observed in which the meteors radiate from a point in the Andromeda constellation. These particles therefore travel round the sun in a period of thirteen years. Slight showers occur about the beginning of August in every year, reaching a maximum on August 10th. This is because the meteoritic particles extend completely round the sun, so there are always some in the way of the earth as we pass through the point where the meteor orbit cuts ours. These meteors radiate from the constellation of Perseus. Another well-known shower happens in April, the radiant in this case being in the constellation of the Lyre.

After a laborious investigation, it was proved by the late Prof. Adams that the Leonid meteors observed in 1866 belonged to a swarm of meteoritic particles which revolved round the sun in an elongated ellipse once in thirty-three years. With regard to the dimensions of the stream, its comparison with the orbit, Dr. Stoney has remarked that a thread of fine sewing-silk, about one foot and a half long,

creeping along an ellipse having a length of seven feet, represents the proportion of the two.

At the beginning of 1866 a comet was discovered by Tempel, and the form and position of its orbit was calculated. Shortly after the memorable meteor shower of 1866, two astronomers, Peters and Schiaparelli, pointed out that the orbit of the Leonid swarm was precisely the same as that of Tempel's comet. There could be no doubt about the matter. In form, dimensions, inclination to the ecliptic, and position, the orbits of meteor swarm and the comet were identical. Only one conclusion could be drawn from this coincidence, namely, that the comet is part of the meteoritic stream. Schiaparelli followed up this remarkable result by calculating the orbit of the August meteors, the Perseids. A comparison of the computed orbit with that of the great comet of 1862 showed that the two were identical. This, then, was a second clear case of a comet being nothing but a swarm of meteorites. A third coincidence of a similar character is still more striking. It is the case of Biela's comet. On November 27th, 1872, and on the same day in 1885 and 1892, shooting-stars showered copiously from a point in the constellation Andromeda. Calculations show that the orbit of this swarm is identical with that of the lost comet, and astronomers now declare their belief in the unity of the two phenomena by naming the Andromeda meteors Bielids. A few other meteor-swarms have been found to move in the same orbits as comets; hence it seems probable that all comets are similarly constituted. Schiaparelli thinks that the comet of 1862 is a large meteorite in the Perseid swarm, but the idea generally accepted is that this comet, and others related to meteor-swarms, represent the densest portion of the swarm.

It is held by some astronomers that meteorites are por-

tions of matter ejected from volcanoes on the earth, moon, or planets. Believers in this theory support also the idea that periodic comets are products of eruptions, hurled into space with such force that they got outside the sphere of attraction of the body which gave them birth. A velocity of six miles a second suffices to carry a body beyond the domain of terrestrial influence, and one mile a second in the case of the moon. Recent researches, however, indicate that meteorites and comets are captured from outer space by the attraction of our system in the manner previously explained.

A comet in passing around its orbit undergoes various transformations. These changes are perfectly explained by the "meteoritic hypothesis." A cloud of meteorites is pulled into the solar system from interstellar space, and is first seen as a fairly luminous haze. The luminosity is produced by the meteoritic particles jostling one another, and thus provoking sufficient heat to volatilise their constituents. The swarm moves onward, and by the increased intensity of gravitational attraction, the individual particles are caused to move faster, and, therefore, to collide and graze against each other more frequently, the result being an increase of brilliancy. As the temperature rises, and a greater amount of heat is developed, the vapours are given off in sufficient quantity to form a tail. Usually this appendage increases in size until a few days after the swarm has passed its point of nearest approach to the sun, and then diminishes. The collisions gradually become less violent and less frequent when the swarm is leaving the sun, and, finally, the commotion has decreased to such an extent that only a feeble luminous haze tells of the swarm's existence.

Professor Lockyer has given additional support to the view that comets are swarms of meteorites by a number of

spectroscopic observations. He placed some fragments of undoubted meteorites in a glass tube, from which the air was afterwards removed by means of an air-pump. The fragments were then, as near as possible, in the condition of similar particles in space. They were gradually heated, and the light which emanated from them was analysed by a spectroscope. The sequence of changes observed under these circumstances were found to be the same as had been seen in the spectra of different comets. A couple of comets at a great distance from the sun have exhibited light of the same quality as that seen as soon as a meteorite is heated in the laboratory, and comets very near to the sun possess a spectrum like that given by meteorites exposed to a high temperature. All the changes in the quality of a comet's light are shown by Professor Lockyer to be those which must occur when a swarm of meteorites has its temperature varied, hence the conclusion that comets and meteorites are "one and the same phenomenon" finds support in spectroscopic observations as well as in orbital coincidences.

Though the superstitious fear of comets has died away, a dread exists in the minds of many people that the earth will some day pass through the nucleus of one. There is certainly a possibility of this happening, and Professor Newcomb estimates it in this manner, "There is hardly a possible form of death which is not a thousand times more probable than this. So small is the earth in comparison with the celestial spaces, that if one should shut his eyes and fire a gun at random in the air, the chance of bringing down a bird would be better than that of a comet of any kind striking the earth."

It is difficult to say what the result of running full tilt into a comet's nucleus would be. If the nucleus consists merely of "cosmic dust," only a brilliant shower of shoot-

ing stars would be seen; but if it is made up of bodies as large or larger than cannon-balls, the consequence would be serious. Myriads of the meteoritic masses would beat upon the earth, and the burning of the materials of which they are composed would probably use up the oxygen in the atmosphere, in which case, man and all the animal creation would perish. The temperature of the air would also be raised to such a degree that all vegetation would be destroyed and our beautiful globe would be transformed into a desolate and barren rock. The prospect is not a pleasant one, and consolation is found in the fact that an encounter such as that referred to only has a chance of happening once in about twenty millions of years.

CHAPTER VII.

IN BOUNDLESS SPACE.

"PROFUSELY scattered o'er the blue immense," above and below the system of the sun, to the right and to the left of it, roll the stars, which are the poetry of heaven. They are suns like our own, shining with unborrowed light, and, very probably, each "informs a system in the boundless space," like that of which the earth is a part. The sun is more brilliant than any star, because it is nearer to us. Take the glorious orb of day away into the infinitude of space, and it would lose its magnificence; tarry not with it until the distance of the nearest star is reached, and it will have dwindled to a lucid point like the pole star, which for ever twinkles in the northern sky.

As soon as Galileo turned his telescope towards the heavens, he saw revealed a host of stars on which no human eye had previously gazed. In his "Sidereal Messenger" he gives a few examples of these virgin regions. Let the discoverer give his own description of what he saw in one of these cases:

"I have selected the three stars in Orion's belt and the six in the Sword, which have been long well-known groups, and I have added eighty other stars recently discovered in their vicinity, and I have preserved as exactly as possible the intervals between them. The well-known or old stars, for the sake of distinction, I have depicted of larger size,

and I have outlined them with a double line; the others, invisible to the naked eye, I have marked smaller and with one line only. I have also preserved the difference of magnitude as much as I could."

By the invention of the telescope, then, the number of

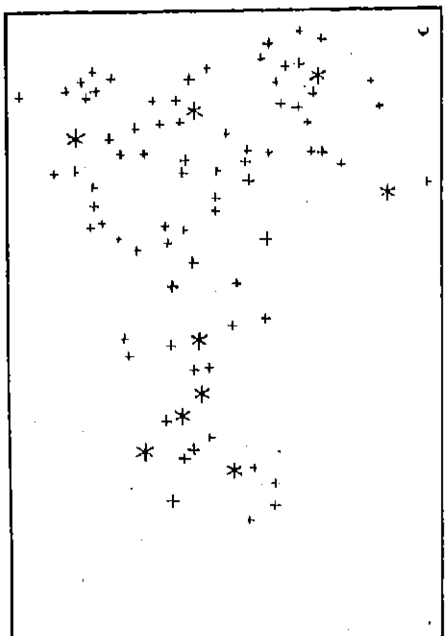


Fig. 28.—" I have selected the three stars in Orion's belt, and the six in the Sword, and I have added eighty other stars." (Galileo.)

observable stars was enormously increased. To the naked eye, between two and three thousand stars can be seen at one time and place. In the portion of the celestial sphere visible from England, about fourteen stars are conspicuously

bright; fifty shine with a light equal to that of the pole star, and two thousand are just visible. Stars are classified into "magnitudes" according to their glory. Those which have an intensity equal to Aldebaran are stars of the first magnitude; the pole star is of the second magnitude, and stars on the verge of invisibility belong to the sixth magnitude. The range of unaided vision thus includes six magnitudes. Astronomers have made an arbitrary distinction between each magnitude and the next. It is decided that the light of a star of any magnitude shall be to the light of a star one magnitude fainter as two and a half is to one. Hence, two and a half stars of the sixth magnitude equal in brightness a single star of the fifth magnitude; two and a half of the fifth equal one of the fourth; and so on until we arrive at a star of the first magnitude, that is, one which sparkles with one hundred times the intensity of a star which can just be seen on a clear night. Telescopic stars are similarly graded, according to the light with which they shine. It is a remarkable fact that down to the tenth magnitude the stars increase in number as they diminish in brilliancy. This is somewhat analogous to what we find in the animal creation. Immense animals, such as elephants, being far less numerous than smaller ones.

The total light received by the earth from stars visible and invisible to the unaided eye is extremely small. Sixty times the total starlight on the clearest night would be required to equal the light of the full moon, and 33 million times the amount to equal sunlight. It is therefore absurd to believe that the stars were created to light the earth. As Lytton tersely puts it, "A farthing candle is more convenient for household purposes than all the stars."

Why is it that "one star differeth from another in glory"? The first explanation which suggests itself is that the differ-

ence in brightness is caused by difference of distance from the earth. A first magnitude star removed to ten times its present distance from us would glimmer as a star of the sixth magnitude, and if taken far enough into the depths of space, it would sink beyond the reach of our largest telescopes. Hence, by assuming that all the stars are equal in size, and that the difference in brightness is the result of difference in distance, it is possible to estimate the relative distance of stars from the earth. These assumptions were for a time indulged in, but they are now known to be fallacious. There may be as great a difference between the sizes of stars as there is between a marble and the earth. What is more, the measures of stellar distance show that many bright stars are much farther from the earth than fainter ones. Stars are seen in the heavens in bunches, and though there is clear evidence that the individuals are at approximately the same distance from the earth, some of them are brilliant while others are scarcely visible in the best of telescopes. The intrinsic luminosity of stars also differs on account of the difference in their temperatures. There are intensely hot stars, and stars which have but their power of shining, owing to their cooled condition, and every gradation exists between the two classes. It cannot, therefore, be definitely said that one star is fainter than another because it is more distant from us, or because it is smaller, or because its surface is less luminous, for each of these causes affect the result.

Stretching across the sky is seen an irregular band of faint luminosity known as the Milky Way or Galaxy. Ancient philosophers speculated and cavilled on the constitution of this belt of milky brightness, and it was not until the invention of the telescope that its true character was declared. "By the irrefragable evidence of our eyes,"

says Galileo, "we are freed from wordy disputes upon this subject, for the Galaxy is nothing else but a mass of innumerable stars planted together in clusters. Upon whatever part of it you direct the telescope, straightway a vast crowd of stars presents itself to view; many of them are tolerably large and extremely bright, but the number of smaller ones is quite beyond determination." The larger telescopes now employed bear out Galileo's observation and show this celestial zone "powdered with stars." About ninety per cent. of all the stars in the heavens lie in or near the Milky Way. As we recede from it in the celestial vault, the stars become less numerous and are fewest when we are at the poles of the galactic circle. To account for this, Sir William Herschel assumed that the stars were of approximately the same size and intrinsic luminosity but at different distances from the earth, and used his telescope as a "sounding-line" to fathom the depth of the stratum of stars in the Milky Way. His observations led him to conclude that our universe extends farther in the direction of the Galaxy than elsewhere. The stars there appear closely packed and of every grade of brilliancy, because they lie one after another in nearly the same direction for a greater distance than in any other part of the sky. Herschel, therefore, supposed the solar system to be situated not far from the centre of a congery of stars, most extended in the direction of the Milky Way and least extended near the galactic poles. This was regarded as our particular universe, and beyond it other universes were supposed to exist. Herschel's conclusions were built upon suppositions, and the result is that many of them are seen to be incorrect when viewed in the light of latter-day knowledge. It can hardly be said, however, that anything

very definite is known concerning the form of the sidereal universe even at the present time.

The determination of the distances of stars is one of the triumphs of modern astronomy. The principle of the method is simplicity itself. To find the distance of a terrestrial object without direct measurement, theodolites are taken to each end of a line, the length of which is known, and pointed to the object, and from the observations the required distance can be found. If two theodolites, say, ten miles apart, are pointed at a particular star, it would seem that the distance of the star could be calculated in the same way as that of the terrestrial object. Observations of this kind would show, however, that the two theodolites were parallel, proving that the star has no parallactic displacement when viewed at the two extremities of a line ten miles long. Enlarge the base-line to one hundred miles, and again the negative result is obtained. Observe the star from the ends of a diameter of the earth, that is, at the extremities of a base-line eight thousand miles long, and still no displacement will be found. But there is another base-line which, it might reasonably be expected, would be long enough for the determination of distances of almost infinite magnitude; it is the diameter of the earth's orbit. The earth is at a particular part of its orbit at the present moment; in six months it will be on the other side of its orbit, the distance between the two points being about 186 millions of miles. If, then, a telescope is directed to a star at an interval of six months, it would seem that a very definite parallactic displacement ought to be observed. So it seemed to Tycho Brahe, and Galileo, and Hooke, Molyneux and Bradley, Herschel, and a host of other astronomers, yet time after time was the observation made without the obtaining of a single accurate result. The failure was partly due to the

imperfections of the instruments employed in the measurement of minute dimensions on the celestial sphere. It was not until 1838 that the problem which had chafed astronomers since the time of Copernicus was satisfactorily solved. But before going further, let us state the means by which the results have been attained.

On account of the movement of the earth in its orbit, we constantly observe the stars from different points in space.

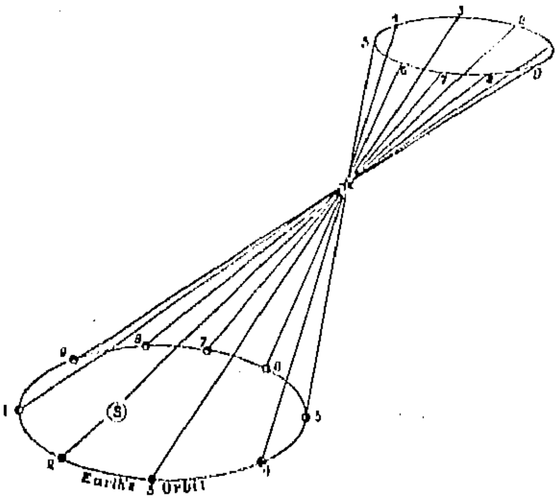


Fig. 29.—"On account of the movement of the earth in its orbit, each star appears to describe annually a minute ellipse on the background of space."

Once a year only do we see them from the same place. For this reason each stellar point is projected upon different parts of the infinite celestial sphere throughout the year. Suppose that on every night in the year a straight line could be drawn from the earth through a star to the celestial sphere,

then the ends of the lines would mark out a figure upon the sphere exactly like that of the earth's orbit. The nearer a star is to the earth, the greater is the size of this apparent ellipse, known as the "parallactic ellipse." Each star appears to describe a minute ellipse of this character, traversing its apparent path annually. It must not for a moment be supposed, however, that these lines of travel can be detected with the naked eye, or that they alter the configuration of the constellations during the year. They are so small as almost to defy detection with the finest of telescopes. To determine the size of the parallactic ellipse of a star, measures are made of the star's exact position (right ascension and declination) throughout the year. A number of corrections have then to be applied to the observations. When this has been done, if the star is not at an infinite distance from the earth, the positions will be found slightly different on different dates, and by mapping the points down upon a large star-chart, they will be found to arrange themselves in the form of a minute ellipse. The angular dimensions of half the longest length of this ellipse is the parallax of the star under observation. It represents the angle contained between two lines drawn from the star, one to the sun, the other to the earth. This method of determining stellar parallax is known as the "absolute" method, because absolute observations of position are made. Unfortunately, it does not give the best results. The vitiating causes are so many, and their effects are so large and imperfectly understood that a star's parallactic ellipse cannot generally be extricated from the tangle.

The "differential" method of determining parallax is free from many of the objections which accrue to the observation of absolute places of stars, and is the one now usually employed. Let us give an illustration of the principle

underlying it. Imagine yourself in a field and looking towards a tree a few hundred yards away. The tree appears in a line with others a considerable distance off. By changing the point of observation, the nearer tree will appear in a line with others. The trees can represent stars at different distances, and by walking round in a circle, the motion of the earth in its orbit can be imitated. Just as a tree appears to change its place with respect to more distant ones as the observer moves round his path, so a star must appear to vary its position with reference to others deeper in space, in consequence of the earth's orbital motion. A difference exists, however, between the two cases. There is no difficulty in telling which tree is near and which is at a distance, but no sure indication of this kind is exhibited by the stars. It is necessary to assume that the faint stars round the one whose parallax is desired are so far away that they can be considered as reference points upon the celestial sphere. The positions of the selected stars with respect to these points are determined throughout the year instead of finding the exact situation in the heavens from time to time. The vitiating causes which debar the result in the absolute method are thus entirely obviated, for they affect all the stars alike. When such measures are made and mapped, the star under observation is found to describe a parallactic ellipse relatively to the faint ones near it. In no case, however, can the true parallax of the star be obtained by this method, but only the difference between its parallax and the parallaxes of the reference stars.

The late Professor Pritchard very successfully used photography in the determination of stellar parallax. Instead of determining the relative positions of stars surrounding that selected for observation, when the objects are in the field of view of the telescope, a photograph was taken, and

the relative positions of the stars upon it were afterwards measured at leisure. The photographs have the advantage of being permanent records, so the measures can be verified if necessary, whereas measures made while the observer is at the telescope have to stand on their merits, for it is impossible to exactly realise the same conditions of observation at any future time.

In 1838, Bessel completed a series of observations of the position of a star known as 61 Cygni, barely visible to the naked eye, with respect to a couple of fainter stars near it. The result showed that half the greatest length of the parallactic ellipse, that is to say, the parallax of the star, was about one-third of a second of arc. To put it another way, if an astronomer were on the star, the angle between the two directions in which he would have to point his telescope to view the earth and the sun respectively would be about one-third of a second of angular measure. Let us give an illustration of this almost infinitesimally small angle. The long hand of a watch moves through a circle of 360 degrees in an hour; in one minute it moves through an angle of six degrees; in one second through one-tenth of a degree, that is, six minutes of arc. Following up this proportion, it will be found that the hour hand moves through an angle of one-third of a second of arc in about one-thousandth of a second of time. In other words, the difference between the directions of the hour hand of a watch or clock at the beginning and the end of one-thousandth part of a second represents the parallax of the star 61 Cygni. We can go further and say that up to the present time no star is known to have a parallax of more than one second of arc—an amount through which the hour hand of a watch moves in the three hundred and sixtieth part of a second. About the same time as Bessel's results were published, Struve, using the same differential method, found

a parallax of about one-fifth of a second for the bright star Vega; and Henderson, by a discussion of absolute measures of position, showed that the star Alpha Centauri, invisible in our hemisphere, has a parallax of rather less than one second of arc.

When the parallax of a star is known, the corresponding distance in miles can be calculated. It can be proved geometrically that any object viewed at a distance of 206,265 times its own length subtends an angle of one second. Thus, a halfpenny has a diameter of an inch, and if the coin is taken to a distance of 206,265 inches, that is, 3¼ miles, the angle between two pointings of a telescope, one to the upper and the other to the lower edge, is one second. Suppose, then, an observer on a star found that the angle between two pointings to the earth and sun respectively was one second; if he knew that the distance from the earth to the sun is 93 millions of miles, he would be able to find the distance of his globe from us, for it would be 206,265 times 93 million miles. Remembering this relation between angles and distance, and also that the parallactic angles are inversely proportional to the distances, it is easy to find the distance of a star after its parallax has been measured. No star has a parallax so great as a single second of arc, hence no star is nearer to us than 206,265 times 93 million miles, that is, about 19 millions of millions of miles. The star 61 Cygni is at three times this distance; Vega is at five times this distance. We cannot comprehend the immensity of these numbers. To bring them within the mental grasp, astronomers employ a unit of length vastly longer than anything used in terrestrial measurements. It is the distance which light travels in a year. In a second of time a beam of light flashes through a distance of 186,000 miles. The space traversed in a year at this rate of motion is a quantity

commeasurable with stellar distances. Upon many maps of towns and suburbs, circles are drawn showing distances in miles from a centre. In London, the distances are generally reckoned from Charing Cross. Let us construct a plan of stellar distances upon this principle, taking the solar system as the centre, but instead of drawing circles representing radii of one, two, three miles and so on, let the distance from the solar system to each circle represent the

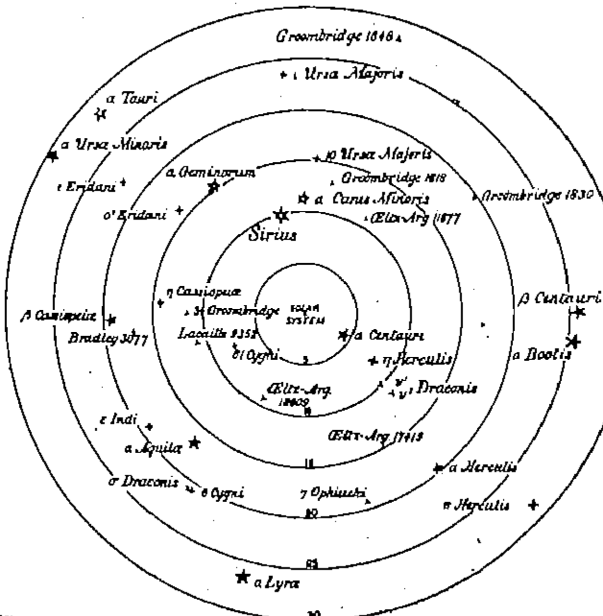


Fig. 30.—"A plan of stellar distances . . the distance from the solar system to each circle represents the span of space through which light flashes from five to thirty years."

span of space through which light flashes in intervals from five to thirty years. We are then able to exhibit upon a

map the stellar distances at present known with any degree of accuracy. Of all the stars, about four score have had their distances determined, and in the illustration those at distances less than that through which light travels in thirty years are shown in their proper relative positions round the sky. More than this, the illustration shows the number of miles the stars are distant from the sun, if the earth's distance were represented by a length of one inch. Alpha Centauri is the nearest star. A flash from the sun to it, or *vice versa*, only takes four years to reach its destination. The light we receive from Alpha Tauri or Aldebaran at the present time left the star on its journey twenty-seven years ago. Or, to put it another way, if the earth is represented by a minute speck of dust revolving round a grain of sand at a distance of an inch, Alpha Tauri would be a similar grain twenty-seven miles away. Most of the stars seen in the sky without telescopic aid are at such a distance that the light we now analyse left them about the time of Galileo; and there are others whose rays, though rushing with lightning speed through the depths of space, only reach us after a journey counted in thousands of years. In a "universe of endless expansion" are we, and through it messages of light may be sweeping from bodies so far sunk in the empyrean that they will never be received by the eye of man.

The appearance of the sky on a fine night gives one the impression of infinite calm and peace, and it hardly appears credible that each orb which we behold is in a state of tumult tremendous beyond our conception, and that all are whirling helter-skelter through space. Yet such are the facts. The stars have apparent motions belonging not to them but resulting from the movements of the earth. They also have "proper motions," that is, real motions which go on quite independently of terrestrial changes of position.

When a vessel is watched on the distant horizon, it only appears to move very slowly, even though the real speed may be great, and, indeed, several minutes may pass without any change of position being detected. Similarly, the stars are so far away that their real motions are scarcely observable, and can only be discovered by watching the skies over a long period of time. Hipparchus made a catalogue of the positions of some of the stars about 125 B.C. Eighteen hundred years later Halley compared these positions of celestial bodies with those found in his day. The comparison showed that unmistakable changes of position had occurred during the interval. The difference between the old and new positions of Sirius, the brightest star in the heavens, was as much as the apparent diameter of the moon, and other stars exhibited similar and even greater discrepancies. The numerous observations made by Hipparchus of the same star precluded the idea that he had been mistaken in his measures; hence the idea that the stars themselves had moved was found worthy of acceptation. Observations made since the time of Halley have established absolutely the fact of this motion, and in all good catalogues of stars now compiled, the amount by which each individual orb changes its position in a year is stated. It appears, then, that a "fixed" star is unknown. The result of this is that configurations of stars change with the lapse of ages. To the eye, the Great Bear constellation appears much the same to-day as it did when Hipparchus observed it more than two thousand years ago. But in, say one hundred thousand years, the familiar Plough, mighty Orion, Cassiopeia's Chair, and other constellations, will have lost their present alignments and be unrecognisable.

The star having the largest proper motion is No. 1830 in a catalogue made by Groombridge, and is, therefore, known

as 1830 Groombridge. It is situated in the Great Bear, but is invisible to the naked eye. In a year this star moves through seven seconds of arc; in a century therefore it moves through seven hundred seconds, and in about 185,000 years it will make the circuit of the celestial sphere. The star 61 Cygni, to which reference has previously been made, has a proper motion of five seconds of arc per annum. It was on account of the existence of this comparatively large proper motion that Bessel was led to select this star for observations of parallax. If the velocities with which stars move across the line of sight were equal, then a large proper motion would be an indication of nearness to our system, but this criterion is no more certain than that obtained from a consideration of stellar brightness.

The stars possess proper motion; the sun is a star, therefore the sun has a proper motion; this is a logical conclusion which presented itself to the mind of Sir William Herschel and which he established by observation. He proved that the sun with his planets and satellites is moving towards the constellation Hercules. A number of determinations have been made of the point towards which the sun is travelling (known as the "apex of the sun's way") by various astronomers, and, considering the difficulty of the problem, the agreement is remarkable. Recent work in this direction indicates that the apex is close to the bright star Vega. The velocity with which the sun is moving may be anything from about five to twenty miles per second. A reasonable estimate makes it about ten miles a second. When we compare this with the rate of a cannon ball it seems enormous. Such a comparison, however, leads to erroneous ideas. A cannon ball which took a day to move through a space equal to its own diameter is travelling at less than a snail's pace, yet with a velocity of ten miles per second, the

sun takes a day to move through a space equal to its own diameter. In order to understand the conditions of the problem which Herschel solved, consider an observer to be in a large park among a concourse of people. The people are moving about in all directions, but a general movement is also noticed away from the entrance gate of the park and towards the exit. This is what is found in the case of the stars. Each star has a motion of its own, and when these motions are considered in hundreds, a general movement from our point in the sky and a general movement towards a point on the opposite side of the celestial sphere is observed. The apex of the sun's way is the part of the sky in which the stars appear to be spreading out, owing to the motion of our system towards them, and the anti-apex marks the opposite part of the sky. If the stars were fixed, like trees in an avenue, the opening out would be similar to that observed in front when walking down the avenue, and the closing up would be analogous to the view behind. The problem would then be a very simple one, whereas the reality of stellar motions makes it very difficult.

Many of the stars undergo changes of brightness ; they are "variable stars." Some fluctuate very considerably in brilliancy ; others are not so conspicuously changeable ; some rise and fall in light-giving power in the course of a few days ; others slowly increase and as slowly decrease in splendour, taking several months to do so. In addition to the stars which periodically swell and shrink in importance, there are those which live a brief life and then "cease to be," and are known to astronomers as "new stars." When Galileo turned his telescope towards the sky, he saw hundreds of stars previously unknown to man, and in our day increased optical powers and celestial photography are continually bringing new worlds within our ken. Such,

however, are not known as "new stars." The term is reserved for those which suddenly blaze out and then slowly fade away to invisibility. Less than a dozen temporary stars of this character have been recorded in historic time. The first of which anything like a circumstantial account was written appeared in 1572 in the constellation of Cassiopeia. During a short part of its existence, this star was so bright that it could be seen in the daytime, and it took fifteen months to fade out of sight. Another new star of exceptional grandeur was seen in 1604. Coming to our own times, we have the star which in 1866 was suddenly exalted from the ninth to the second magnitude, and, after occupying this position for about a month, went back into the obscurity from which it had been raised. This was the first new star to which spectroscopic analysis was applied. The increased light was found to be of the quality emitted by hydrogen.

In 1876 a new star appeared in the constellation Cygnus. It was of the third magnitude when at its brightest, and in fifteen months had sunk to the eleventh magnitude. The remarkable fact about this star is that when it had sunk to its lowest degree, and was presumably at a lower temperature than at the time of greater brilliancy, it was indistinguishable from a small nebula or a comet when far away from the sun.

A stellar visitor appeared near the centre of the great nebula in the constellation Andromeda in 1886, but did not become bright enough to be seen with the naked eye. In about four months it entirely vanished, though not without reporting that its light was the same as that of the nebula itself.

A considerable amount of interest was taken in a new star observed in the constellation Auriga in 1892. The analysis of the light of this star showed that we were really viewing two or more bodies moving with different velocities and in different directions with respect to the earth. The

star is still visible, but, like the new star of 1876, it has assumed the condition of a small nebula, its light being of precisely the same quality as that given by these cloud-like patches in the sky.

To account for the phenomena of new stars, various theories have been propounded. Some astronomers believe that the increase of brightness is caused by an enormous outburst of luminous material from a faintly luminous crust, or the shooting forth of a great mass of luminous hydrogen in a similar manner to that observed in eruptions on the sun, but on a larger scale. Prof. Lockyer has suggested that new stars are caused by the accidental meeting of two swarms of meteorites in space. When the collision occurs, a large amount of heat is developed, and the luminosity is increased so long as the swarms are passing one another. After the conflict, normal conditions prevail, the swarms travelling "every one to his own way."

The most celebrated star which waxes and wanes in brightness in a period of several months is in the constellation Cetus, and is known as Mira Ceti—the wonderful star of Cetus. It is a typical "variable of long period." At the time of maximum brightness Mira is usually of the second or third magnitude, and sometimes rivals a star of the first magnitude. It then fades gradually away, and in rather more than a couple of months can only just be seen in a three-inch telescope. For nearly eight months the star remains in this unimportant state, when suddenly an increase of brilliancy sets in, and in about a month the star is again in the zenith of its power. Prof. Lockyer's explanation of the cause of this kind of variability satisfies the facts of observation better than any other. It is that the faint star we see for eight months or so is really a swarm of meteorites. Revolving round these jostling rocks in an

elliptic path is a similar, but smaller, congregation. When the smaller swarm passes close to the larger one during its periodic journey, the meteorites rub against and collide with

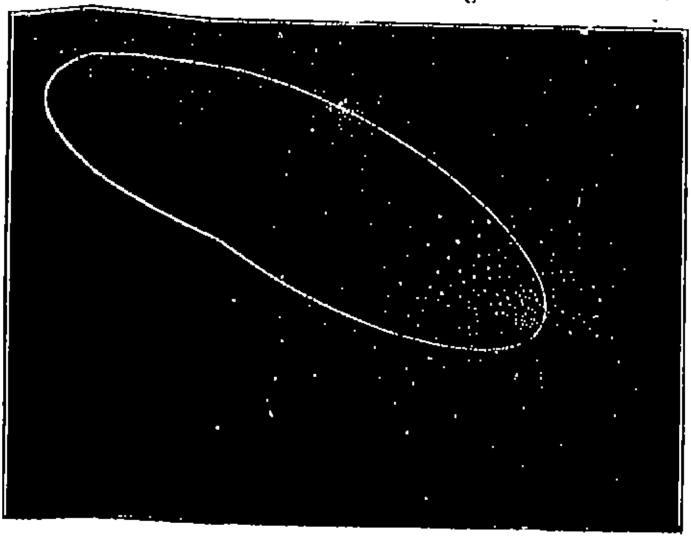


Fig. 31.—"When the smaller swarm passes close to the larger one during its periodic journey . . . increased luminosity testifies to the encounter."

one another. The result is a development of heat; a melting and vaporisation of some of the constituents therefore follows, and increased luminosity testifies to the encounter. The spectroscopic analysis of the light of stars of this character gives support to Prof. Lockyer's hypothesis. During maximum brilliancy a number of bright lines are added to the star-spectrum, and this is exactly what would be expected when two swarms of meteorites pass near enough to one another to drive some of the constituents into vapour and render them luminous.

A variable star of quite a different type is Beta Persei.

The ancients were so much struck by the extraordinary behaviour of this object that they named it Algol, the Demon Star. For two and a half days Algol is of the second magnitude, and conducts itself like an ordinary star. Suddenly, however, it begins to lose its power, and in about four and a half hours it sinks nearly two magnitudes. But in less than half an hour the Demon Star commences to climb into its former position, and in about four hours the goal is reached. These changes are run through in 2 days, 20 hours, 48 minutes, 51 seconds.

More than a century ago Goodricke suggested that the apparent changes of Algol's light were caused by a dark body revolving round the star, and once in a revolution coming between it and us, and so causing it to be partially eclipsed. This theory has been established by Prof. Pickering at Harvard, Prof. Vogel at Potsdam, and Mr. Maunder at Greenwich. Algol has been proved to approach and recede from the earth in a period the same as that of its variation in light. It swings away from us and blinks, then rushes towards us, only to run away and blink again. The oscillations are caused by Algol's dark companion. The dark star and the bright one are connected by gravitational attraction, as if by a long rod, and both move round the point on which the rod could be balanced; hence, when one is moving towards the earth, the other is being swung back. The spectroscope

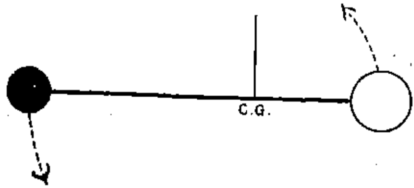


Fig. 32.—"The dark star and the bright one are connected by gravitational attraction, as if by a long rod, and both move round the point (C.G.) on which the rod could be balanced."

shows that Algol is receding from us when the dark body is coming forward to eclipse it. After the eclipse has occurred the dark star is being whirled away from the earth and Algol is approaching. It may be necessary to point out that the fluctuations of brightness are by no means caused by Algol alternately approaching and receding from the earth. The star is of the second magnitude, both when it is moving towards us and when it is running away from us.

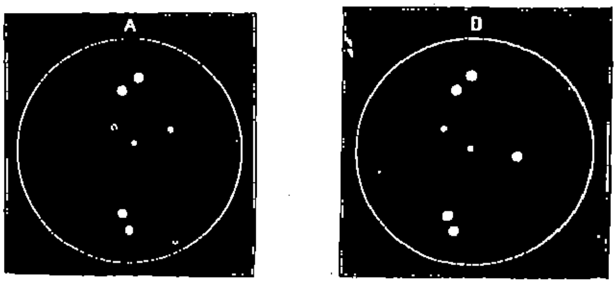
Algol and its dark companion are an ill-matched pair. Itself in the prime of life, but chained to an old world which swings it hither and thither and gives it a bad name, whereas, had it not been so mated, it would behave like a staid and respectable member of stellar society.

In addition to stars like Algol, which have been proved to be under the influence of invisible companions, there are many double stars "whereof the one more bright is circled by the other." Such are known as "binary stars," or binaries. Sir William Herschel was the discoverer of these revolving systems. He measured the distances between a number of stars which appeared close together when telescopically observed, and also the direction of the line connecting them. Repeating the measures after a time, he found that the separating distances and the direction of the connecting lines of pairs of stars had altered. Further observations proved beyond doubt that the component stars were slowly moving round their common centre of gravity, and at the present time between two and three hundred pairs of these distant suns have been observed to change their positions and directions in a similar manner.

When Herschel took up the observation of double stars, he did so with the idea of determinating stellar parallax by the differential method afterwards successfully used by Bessel. In his day, double stars were considered to be

double because the two objects happened to lie in nearly the same direction, and systems of revolving suns were unrecognised. Some of the stars which appear to be double must be of this kind, that is, they are not really companions having a stately waltz in space, but only "optical" doubles. The orbits of a few "physical" doubles or binaries have been calculated, and the time of revolution found to vary from about fifteen years to as much as two thousand years.

Though only comparatively few double stars have been observed to complete a revolution or move in curvilinear



1842. 1873.

Fig. 33.—Views of ε Lyræ on two different dates.

paths round a point between them, more than ten thousand double stars are known and have had their distances and directions determined. As time goes on these measures will be compared with others to see if any changes have occurred during the interval.

Sirius has a peculiar history. Observations of its position indicated that it did not merely move in a straight line, but travelled in a small curved path, and in 1862 the minute but ponderous body which hampered its movements was discovered by Alvan Clark. The period of revolution of the Sirian system is about fifty years. Procyon is a similar

star of which the small or dark companion has not been discovered.

Castor, one of the Heavenly Twins, is a good example of a binary star. To the naked eye it appears to be a single star, but when viewed telescopically it is seen to be made up of two, one a magnitude brighter than the other. The period of revolution of this pair is about one thousand years. Alpha Centauri, the star nearest to our system, is also a

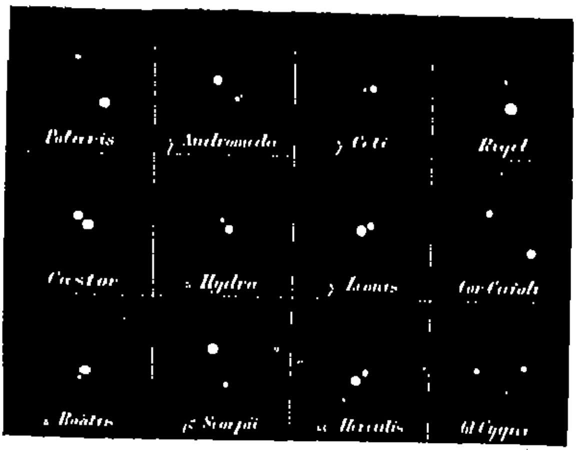


Fig. 34.—A selection of double stars.

double, the period of revolution being about eighty years, and the mean distance being about twenty-three times greater than the distance of the earth from the sun. The star Epsilon (ε) Lyræ is very interesting. An observer gifted with acute sight can see that this object consists of two, without the aid of a telescope. By means of an opera-glass the duplicity is at once made out, and if a telescope of moderate dimensions is employed, each of the pair is seen to consist of

two, thus making the system a quadruple one. On this account the star is known as "the double-double." Each pair is revolving round the common centre of gravity, and at the same time the individuals of the pair are in motion round one another.

The components of a large number of double stars usually differ in colour when they differ in brightness. Beta Cygni is a beautiful example of this. When viewed in a small telescope, the star is seen to consist of two, one of the third, the other of the sixth magnitude. The brighter star has a golden-yellow colour, while the fainter companion is blue. Gamma (γ) Andromedæ is another but more difficult example of the same kind. Its components are respectively of the third and fifth magnitudes, the larger being yellow and the smaller sea-green.

"Nature finds gladness in a thousand tints." This applies to celestial as well as terrestrial objects. We have stars of a bluish-white colour like Capella; of a bluish-green like Sirius; red, like Aldebaran; and yellowish-red, like Arcturus, and between one and the other there are shades innumerable. Like the flowers of the earth are the flowers of the sky, exquisite in their beauty and variegation.

From double and multiple stars we pass to "clusters and beds of worlds, and bee-like swarms of suns." The Pleiades is a cluster in which six bright stars can be counted without telescopic aid. In the constellation of Cancer is a close congregation of stars which appears like a spot of light when viewed with the unaided eye. An opera-glass shows that the spot consists of forty or fifty individual stars, and a telescope of moderate dimensions will show hundreds of stars packed in a small space. Another well-known object of this kind is found in Perseus. It is a double cluster of stars, and can be fairly well seen with a good field-glass.

More interesting than any of these objects is a globular cluster of stars in Hercules. In a small telescope, this cluster looks like a round patch of haze, but with a large one several thousand stars can be seen and counted.

Very similar in appearance to a star cluster seen with a telescope are the celestial objects known as "nebulæ—" this word being the plural of a Latin one meaning a cloud. They are faint patches and wisps of luminous haze set in the starry vault and playing a most important part in the universe. It must not be supposed that these celestial clouds are so transient as those of the earth. Changes doubtless happen, but from the time when nebulæ were first observed to now, no striking differences have been found.

Two nebulæ can be distinguished with the naked eye, one in Andromeda, the other round the middle star in the sword of Orion, Theta (θ) Orionis. A small telescope shows that this star is really composed of four, arranged in the form of a trapezium, and a large instrument adds two more. Surrounding the star will be seen an irregular area of mist—the Great Nebula of Orion. The Andromeda nebula is more easily seen with the naked eye than the Orion nebula though it does not cover such a large area of sky. In a moderate-sized telescope the nebula is seen to be a spindle-shaped mass of luminosity. Another interesting nebula occurs between Beta and Gamma Lyræ. It is ring-shaped and somewhat like the rings of smoke which many smokers can blow from their mouths. In addition to the irregular, elliptical, and ring-nebulæ, exemplified by the foregoing examples, there are a few objects having a spiral or whirlpool form, and more or less round patches known as planetary nebulæ, on account of their showing discs of almost uniform brightness. Nebulous stars have the appearance of points of

light shining through a mist, and many bright points have wisps and lucid streams running out from them in curves and lines too diverse in character to admit of classification. Double nebulæ close together and far apart are also found in all sizes.

About seven thousand nebulæ are now known, and it is a remarkable fact that they are much more numerous in the parts of the sky distant from the Milky Way than in or near it.—Where stars are abundant, nebulæ, as a rule, are scarce, and in the regions in which nebulæ are found the heavens lose their richness as far as stars are concerned.

Many clusters of stars, which look like nebulæ when viewed with a small telescope, are found to consist of individual stars if a larger instrument be employed. This led to the idea that nebulæ are clusters of stars so far removed from our system as to be beyond the disintegrating or resolving power of our largest telescopes; hence nebulæ were divided into two classes, one containing those which had been resolved or broken up by optical aid, the other containing objects which defied disintegration. This classification, however, is not now maintained, for the spectroscope has shown that the light of nebulæ is not that which would be received from clusters of stars. The criterion as to whether an object is a nebula is, therefore, the light badge revealed by the spectroscope, and not the telescopic appearance. More is said on this point in the next chapter.

CHAPTER VIII.

CHEMISTRY OF STARS AND NEBULÆ.

Every English child has heard the lines, "Twinkle, twinkle, little star, how I wonder what you are," and the wonder is shared by many men and women. To be able to analyse objects, the nearest of which is about 250,000 times farther from the earth than our sun, fills everyone's mind with admiration. Let us trace the history of this marvellous achievement.

In 1814, Frauenhofer, the perfecter of the spectroscope, and the observer of dark lines in the spectrum of sunlight, placed a large prism over the object-glass of a telescope and turned the compound instrument towards Sirius. The light from this brilliant gem of the sky fell upon the prism, traversed the prism, and was separated into its constituent parts, and then passed in this decomposed condition down to the eye of the curious optician. The view was not remarkable, and Frauenhofer hardly realised the importance of his observation. "I have seen," said he, "without any illusion, three dark lines in the spectrum of the light of Sirius which, apparently, have no resemblance with those of the sun's light. One of them is in the green and two in the blue space. Lines are also seen in the spectrum of other fixed stars of the first magnitude; but these stars appear to be different from one another in relation to these lines." Little was added to these facts for half a century, when

Secchi of Rome, and Dr. Huggins, took up the inquiry. The meaning of the dark lines in the solar spectrum was then understood, and astronomers were beginning to recognise the importance of the spectroscope as a weapon of research. The analysis of the light of "the distant suns" followed as a necessary consequence. Dr. Huggins, working with Dr. Miller, found that the spectrum of Sirius consisted of a few dark lines upon a rainbow-tinted ribbon of light. One after another, substances were vaporised and rendered luminous in order to find those which possessed bright lines coincident in position with dark lines in the star-spectrum. Hydrogen was thus shown to be the chief constituent of the Sirian atmosphere, and other elements identified were magnesium, sodium, iron, and calcium. The radiations which reach us from the stars are unintelligible without the spectroscope. Each substance comes to report its existence in its own language, and a babel results from their simultaneous speech. But the spectroscope singles out from this confusion of tongues the different languages, and bids each clamouring voice take up its proper position. The interpreters are then called from the laboratory. The hydrogen language of this earth proves to be that of the skies, and the many inflections in the language of terrestrial iron are found to agree with those in which the light-ambassadors from the denizens of space have been speaking to us for thousands of years. Many other languages of light have been identified, but there are still some for which no interpreter has been found.

Though Secchi and Huggins commenced observations of stellar spectra about the same time, they adopted different lines of work. The latter observer investigated the chemical nature of stars; the former took a more comprehensive view, his idea being to classify the stars according

to their spectra. Four types of stellar spectra were thus established. White stars, like Sirius and Vega, usually possess spectra in which a few broad, dark lines due to hydrogen are conspicuous. Yellow stars, like Arcturus, have spectra in which a large number of fine lines, chiefly due to iron, are visible. If the sun were taken away into space until it appeared of the same brightness as Arcturus, the spectra of the two would be found to be almost exactly alike. Red stars, like Betelgeuse (Alpha Orionis), show spectra entirely different from the first and second types. Instead of lines, dark bands are seen, each of which fades away in the direction of the red end of the spectrum. The fourth type established by Secchi contains a few faint stars of a deep red colour, having banded spectra like the third type, but the bands fading away in the direction of the violet end of the spectrum.

This classification roughly distinguishes the chief kinds of spectra, and is the one generally used at the present time. It is analogous to the division of the animal kingdom into vertebrate or back-boned animals; articulated or jointed animals, like lobsters; molluscs, like snails and oysters; and rayed animals, like star-fish. Each of these divisions contains a number of different classes, and the classes are divided into groups or orders, and there is no saying where one order ends and the next commences. In the same way, there is no sharp distinction between the different types of star-spectra, and though Secchi's arrangement holds good in the main, the spectroscopic discoveries of recent years make a more detailed classification essential. Prof. Vogel has developed a classification which takes in many of the spectroscopic niceties neglected by Secchi, and Prof. Lockyer has arranged spectra on quite a new plan. We return to this subject later on in the chapter.

We have seen that the spectrum of the sun consists of fine, dark lines, and that the spectra of stars are characterised by similar evidence of absorption in their atmospheres. Such and so was the knowledge, when, in 1864, Dr. Huggins turned his telescope, armed with a spectroscope, to a nebula in the constellation Draco. To his astonishment, a solitary bright line appeared instead of a multitude of dark ones. Further scrutiny showed two more bright lines, fainter than the one into which all the light of the nebula seemed to be concentrated. Never was there a more significant observation. Nebulæ had been considered to be stars clustered together and sunk so deep in space as to lose their individuality even when observed with the most powerful telescopes, but the spectroscope gave the *coup de grace* to this idea by showing that the light of nebulæ differed in quality from the light of any stars then known. Having seen the bright lines, and satisfied himself that they were not due to some instrumental defect, Dr. Huggins began his match-making. One of the three lines observed was found to be exactly matched by a line due to luminous hydrogen, and the brightest line seemed to coincide with a line of nitrogen. It was therefore concluded that the nebula consisted chiefly of glowing hydrogen and nitrogen gases. Other nebulæ were examined, and the triplet of lines found in their spectra, the brightest being invariably that supposed to have its origin in nitrogen. It is the brand or badge of nebulæ, and is known as the "chief nebular line." Some of the nebulæ, however, show an unbroken band of colour—a continuous spectrum—with neither bright nor dark lines upon it.

To the three bright lines observed by Dr. Huggins in nebular spectra, later observers have added five more. Three of these lines are certainly due to hydrogen, and one

is the line usually seen in the spectra of solar prominences, and due to an unknown element to which the name of *helium* is given. Spectroscopists are not agreed as to the substances which give rise to the remaining lines; even the origin of the nebular trade-mark is a matter of dispute. Dr. Huggins originally supposed it to be due to nitrogen, and this origin is stated in text-books of astronomy "even to this day." But the nitrogen origin has now been abandoned, for there is no doubt whatsoever that the line in question is not due to this element. Prof. Lockyer has brought forward a large amount of evidence to show that the line reports the existence of magnesium vapour in nebulæ, but other spectroscopists, and notably Dr. Huggins, declare against this view.

In recent years, our knowledge of the spectra of nebulæ and stars has been very considerably extended by photography. A photographic plate replaces the eye of the observer and receives the spectrum upon its sensitive film. By means of specially prepared plates, the lines from the yellow to the violet in the visual spectrum can be photographed at the same time as lines in the invisible part of the spectrum beyond the violet. The colour is not photographed, but the lines can easily be recognised upon the picture, for each occupies its proper relative position. The same holds good in the invisible or photographic spectrum of a star, the relative positions of lines being always the same. We emphasise this point because students have a difficulty in understanding how it is possible to know one line from another in a photograph of a spectrum, since there is no colour guide. The double yellow line of sodium, and the green triplet of magnesium when once seen are recognised forever after. If a specially prepared photographic plate, instead of the eye, receives

the impressions from these lines, the negative obtaine shows the sodium pair and the magnesium triplet as blac lines. But though no colours are exhibited, the sodium pa will be at exactly the same distance from the magnesiu triplet as was observed with the eye. Usually, whe spectra are photographed, none of the lines in the gree yellow, and red parts of the spectrum leave their impre sions upon the plate, but only lines in the blue and viol and those too high in the light-scale to be perceived b the human eye.

Until a few years ago it was held that nebulæ whic show bright lines in their spectra, "are systems possessin a structure, and a purpose in relation to the univers altogether distinct and of another order from the group o cosmical bodies to which our sun and the fixed stars be long." There seemed to be a hard and fast distinctio between a star and a nebula, namely, that the former ha a spectrum of dark lines, while the latter possesses a brigh line spectrum. This division would be allowable but fo the fact that some stars—if the word is not a misnomer have a spectrum exactly like nebulæ, that is, a spectrum o bright lines. The number of "bright-line stars" no known is fifty-four, and Prof. Pickering of Cambridge, U.S who has discovered most of these objects, has suggeste that a fifth type of spectra should be erected to contai them and planetary nebulæ with similar spectra. In th light of these facts it cannot be held that nebulæ ar entirely distinct from stars. There is certainly a conside able difference between a nebula and a star like the sun but the difference is very probably only one of develop ment. The spectroscope shows that nebulæ merge into star and that star spectra of the different types pass by almo insensible gradations one into the other; hence it is as in

possible to say, here one kind of spectrum begins, and there another kind ends, as it is for the naturalist to draw the line of demarcation between the different species of animals. This is now generally recognised. Stars are believed to be evolved from nebulæ, and as they grow old, to change their quantity of light, the spectroscope thus confirming the conclusion arrived at by Sir William Herschel from a study of the telescopic appearance of celestial objects. He found planetary nebulæ merging into nebulous stars, stars surrounded with a large amount of nebulosity, and others possessing but a small hazy mist or halo. Double nebulæ appeared to form double stars, and large masses of nebulosity to break up into star-clusters. In no one case could this development be traced, but Herschel's observations showed that the finished star and nebulæ are connected by such intermediate steps as to make it highly probable that every succeeding state of the nebulous matter is the result of the action of gravitation upon it, while in the preceding one, and by such steps irregular nebulosities are brought up to the condition of planetary nebulæ, from which it passes to a nebulous star, and then to the completed product.

Though astronomers are of one mind as to the evolution of celestial species, they are not agreed as to the constitution of nebulæ, nor as to the relative ages of stars. Dr. Huggins' detection of hydrogen in nebulæ, and the widely-taught statement that nitrogen exists as a luminous gas in these bodies, lead at once to the belief that nebulæ are masses of gas. Every spectroscopist believes that glowing hydrogen is present in nebular light, hence it would seem that nebulæ must be gaseous bodies. But this is not at all certain. Nebulæ may be, and very probably are, composed of innumerable solid particles colliding and jostling one

another, and thus provoking sufficient heat to drive some of their constituents into vapour. When a meteorite is heated, a quantity of hydrogen gas is usually driven off, and can be rendered luminous by suitable means in the laboratory. It is reasonable, then, to conclude that a swarm of meteorites in space, when rendered hot by friction against one another, would evolve hydrogen which would be made luminous, and so be revealed by the spectroscope. Since 1887, Prof. Lockyer has been elaborating this "meteoritic hypothesis." He has subjected meteoritic fragments to varying temperatures, and studied the light they emit, by means of the spectroscope. One of the first lines which became visible is very nearly, if not quite, coincident with the brightest line in the spectrum of nebulæ. This line proved to have its origin in magnesium, hence it was concluded that the chief nebular line is also due to this element, but the coincidence, and the inference drawn from it has been, and is still, hotly contested by other spectroscopists. Let us look into the matter a little closer. A comet, at a great distance from the sun, cannot be distinguished from a nebula by its telescopic appearance. Both look like patches of mist or fog. Further, comets so situated have been found to exhibit the nebular badge in their spectra. Now there is little doubt that comets are annexed from interstellar space; hence it would seem that they are simply nebulæ which have come under the attraction of our system. If, then, it is accepted that comets are swarms of meteorites, we are logically bound to conclude that nebulæ are similarly constituted.

"All self-luminous bodies in the celestial spaces are composed of meteorites, or masses of meteoritic vapour produced by heat brought about by condensation of meteor-swarms due to gravity." This is one of Professor Lockyer's con-

clusions. According to it, we begin with a nebula consisting of a number of solid fragments. The individuals knock and rub against one another like a swarm of gnats in the air. Heat is therefore developed, and the swarm of dark particles gradually become surrounded with luminous vapours. The conflict increases as the swarm condenses; hotter and hotter becomes the fight, until finally all the particles have been battered into vapour. The vaporous globe cools; it sinks to the condition of our sun, of the earth, of the moon. And possibly, though here we have no evidence, bodies in the same stage as our satellite may break up to form meteorites, which, by condensing into groups, would give a repetition of the phenomena, "and so on, *ad infinitum*."

Using this theory of celestial evolution as a groundwork, Professor Lockyer has built up a classification of the spectra of celestial bodies more comprehensive than any other. He divides the spectra into seven groups, each of which merges into the next. The first group contains nebulæ and stars with bright lines in their spectra, both being considered to be uncondensed swarms of meteorites. Group two contains bodies with banded spectra, like Secchi's third type. The temperature is somewhat higher, but the meteorites still retain their individuality. In the third group, dark lines replace the bands, the temperature still increasing, and when group four is reached all the meteorites have destroyed one another, and their constituents exist in the form of vapour. Stars of this group have atmospheres in which hydrogen predominates, as in Secchi's first type. This indicates the highest temperature, and to account for the richness in hydrogen it is suggested that many of the substances we now know as elements are decomposed into hydrogen under such intense conditions. The fifth group

is equivalent to Secchi's second type. It contains stars like the sun, having in their spectra a large number of lines due to iron, and very probably at a lower temperature than those exhibiting the almost unique absorption of hydrogen. Group six have banded spectra like Secchi's fourth type, with carbon as the chief constituent of their atmospheres. Group seven includes bodies like the earth and moon, having no light of their own. Though the conclusions as to the cause of these different kinds of spectra are combated; the fact remains that Professor Lockyer has been able to arrange star-spectra in a continuous sequence from nebulæ up to stars like Vega, and down to bodies on the verge of extinction. Secchi's classification of spectra was entirely founded upon appearance. Vogel's is based upon descending temperatures, all the stars being supposed to have cooled from the condition of Vega. Lockyer bases his arrangement upon the very plausible argument that there are stars increasing as well as decreasing in temperature, and it can stand whether stars are believed to be evolved from meteorites or not.

The means by which the motions of solar vapours are measured are described in Chapter III. The movements of stars towards or away from the earth are similarly determined by the spectroscope. It might be supposed that the criterion of a star's direction of motion is change of brightness. But this is not so. If the nearest star were to approach the earth at the rate of one hundred miles a second, its brightness would not be increased by one-fortieth part in a century, and a motion of recession would only cause the same amount of diminution in this time.

We have said that the lines in a spectrum, like the notes of a piano, have a fixed pitch, which is altered, however, by relative motion backwards and forwards. The distance between

us and a luminous body is immaterial, so long as it remains constant. But if the distance is diminishing, all the spectrum lines are increased in pitch—are shifted towards the violet end of the spectrum, and if it is increasing, a lowering of pitch is the result—the lines are shifted towards the red end of the spectrum. Suppose a piano were being hurried towards us on an express engine with its C note sounding, it would be impossible to say whether the note had its pitch altered by the motion simply by listening to it. If, however, we had a C tuning-fork of standard pitch, any change could be at once detected by sounding it and comparing the note with that received from the moving piano. In the same way, any change of pitch in spectrum lines cannot be found by merely observing or photographing the spectrum. It is necessary to have a spectrum of standard pitch to compare with. This is easily obtained. Hydrogen shows a set of lines in particular positions when we make it luminous in the laboratory. The lines can be considered analogous to the C's of a piano. When we compare this set with those given by the light of some stars, perfect agreement of pitch is often found. On the other hand, the hydrogen lines of certain stars do not coincide with those of terrestrial hydrogen, but appear shifted towards the violet end of the standard spectrum. The obvious conclusion is that the star is moving towards the earth, and by measuring the amount of displacement, the velocity of motion can be calculated. When such a star is moving away from the earth, its hydrogen lines are displaced to the red sides of the lines in the comparison spectrum. In 1868, Dr. Huggins utilised this principle for the determination of the motions of a few stars "in the line of sight," and since 1889 Professor Vogel has very successfully used photography in the investigation. The spectrum of the star whose motion is under determination

is photographed side by side with the spectrum of hydrogen or iron. The displacement of each line of hydrogen or iron in the star-spectrum, with respect to the same lines in the terrestrial spectrum, is then measured, and the mean or average displacement found from the sum of the measures. The motions in the line of sight of about fifty stars have thus been determined with a probable error of about a mile a second. Aldebaran is found by Vogel, and also by Mr. Maunder, of Greenwich, to be running away from the solar system with a velocity of about thirty miles a second, while the star Gamma Leonis is approaching us at the rate of about twenty-four miles a second. The average speed is about ten miles per second.

Prof. Keeler, using the magnificent instrument of the Lick Observatory, has determined the motions of some of the nebulæ in the line of sight. He finds that the Great Nebula of Orion is moving away from the earth with a velocity of about ten miles per second; another nebula seems to be receding at the rate of thirty-eight miles in a second. It is difficult to think that nebulæ can move through space with these enormous velocities, until it is remembered that the finest particle of matter can travel through a vacuum as easily as a solid mass.

In 1889, Professor Pickering found that one of the lines in the spectrum of Mizar, the middle star in the tail of the Great Bear, was doubled at intervals of fifty-two days. It was therefore concluded that the star consists of two very close together, and having the same kind of spectrum. If the pair of stars faced the earth and were in relative rest, a simple spectrum would be observed at all times, for one set of lines would overlap the other. But the periodic doubling of the lines testifies clearly to relative motion. When one of the pair is moving towards us, the other is

being swung away from us. The approaching body has its spectrum-lines displaced towards the violet end of the spectrum, while the lines of the receding one are displaced in the opposite direction. A separation of the lines is therefore seen. When, however, the bodies are moving across the line of sight, no such displacement occurs. Twice, then, in a revolution are the lines at their greatest distance apart, and twice do they overlap one another. The doubling occurs every fifty-two days, hence the time of revolution of the pair of stars round the common centre of gravity is 104 days. The relative velocity indicated by the separation of the lines is about one hundred miles a second, that is to say, each star has a velocity of about fifty miles a second. The stars are about 143 millions of miles apart, but this is far too small for us ever to see them double by means of a telescope.

Beta Aurigae is another star in which the lines are periodically doubled, but in this case the interval is only two days, indicating a period of revolution of four days. Each star has a velocity of about seventy miles a second, and the distance between them is seven and a half million miles. To see Beta Aurigae as a double star we should require a telescope about eighty feet in diameter.

The discovery of spectroscopic binaries is a wonderful achievement, and doubtless the number of stars of this class will be added to in the near future.

CHAPTER IX.

CELESTIAL PHOTOGRAPHY.

THE idea of employing the newly-discovered art of photography for the purpose of obtaining photographs of the sun and moon was first suggested by the French astronomer, Arago, in August, 1839. The results obtained by acting upon the suggestion were far from being satisfactory. Our satellite impressed a feeble outline upon the sensitive surface, but all details were conspicuously absent. So disappointing, indeed, were the pictures that they did not justify the continuance of the experiment. About six months later, however, Dr. Draper, of America, succeeded in getting a representation of the moon's surface, and shortly after he wrote, "There is no difficulty in procuring impressions of the moon by the daguerreotype beyond that which arises from her motion. By the aid of a lens and a heliostat, I caused the moon-beams to converge upon a plate, the lens being three inches in diameter. In half an hour a very strong impression was obtained. With another arrangement of lenses I obtained a stain nearly an inch in diameter of the general figure of the moon, in which the places of the dark spots might be indistinctly traced." The method is very simple. A heliostat, or a siderostat, is a mirror connected with clockwork, which causes it to move in such a manner that the light of a celestial object is constantly reflected in one direction. If an ordinary camera is fixed

pointing towards the north, and a heliostat is arranged in front of it, so as to reflect the light of the moon or any other celestial body straight towards it, the clock will slowly turn the mirror as the body moves across the sky, and thus keep the reflected beams in the required direction. The luminous image of the object will constantly be visible upon the ground glass of the camera, and if a photographic plate is inserted, the rays fall upon the sensitive film and leave their mark. Instead of an arrangement of this kind, a telescope can be used, in which case the whole instrument follows the celestial motions, but some remarkably fine results have been obtained by using a lens precisely similar to that of an ordinary camera but larger.

The advantages of photography over visual observations are many. To begin with, the human eye, considered as an optical instrument, is full of imperfections. It is extremely rare to find the two eyes of a person exactly alike, or to find two people with exactly the same power of seeing. Nowhere is this fact more clearly manifested than in the records of observational astronomy. Fortunately, the photographic plate is unable to exercise the faculty of imagination. It infallibly records the impression received. If the lens of the camera or the telescope is imperfect, the image of an object is also imperfect, and the photographic picture obtained testifies to the fact. Another advantage of the photographic plate over the human retina is that its range of sensibility is greater. We cannot perceive luminous vibrations more rapid than those which produce the impression of violet light, or slower than those which give us the sensation of deep red light, whereas an ordinary photographic film is sensitive to vibrations within our range, and to others far beyond it which are utterly powerless to produce any visual effect. Further, a peculiar advantage of

the photographic plate is its ability to accumulate impressions. The human eye soon tires, the best view of an object being generally obtained at first sight. With a sensitive film, the reverse is the case. The light of an object may be so faint as to be unable to be grasped by any observer with any telescope. It may not leave any mark upon the photographic plate after beating upon the sensitive surface for an hour, but let the action continue for a longer time, and that which was invisible will be revealed. There seems to be no limit to this accumulative effect. Apparently blank spaces in the sky have been shown to be filled with stars and faint nebulosities telling of the infinite extent of the universe.

Celestial photography began with the obtaining of pictures of the moon, so it may be as well briefly to mention the chief work which has been done in this direction. After the discovery, in 1850, of surfaces more sensitive to light than those used by Arago, lunar photography grew apace. In 1857, Warren De La Rue, an English astronomer, began to produce detailed representations of the lunar surface, which have rendered his name immortal. Numerous pictures of the moon an inch in diameter were obtained, and many of them were afterwards enlarged up to sixteen inches. The fine sensitiveness of the photographic film employed is shown by the fact that instantaneous pictures of the full moon were obtained, and an exposure of only twenty or thirty seconds was sufficient to produce a beautiful picture of the crescent moon. Each of De La Rue's photographs is a work of art, and the many details they contain give them a high scientific value. They clearly demonstrated the applicability of photography to the celestial bodies. While De La Rue was working in England, Rutherford was producing excellent pictures in America. Dr. Henry Draper, the son of the distinguished

physicist to whom reference has been made, then took up the matter and obtained some beautiful photographs of our satellite. Though many astronomers photographed the moon after Draper, little was added to our knowledge until 1889, when the large instrument of the Lick Observa-

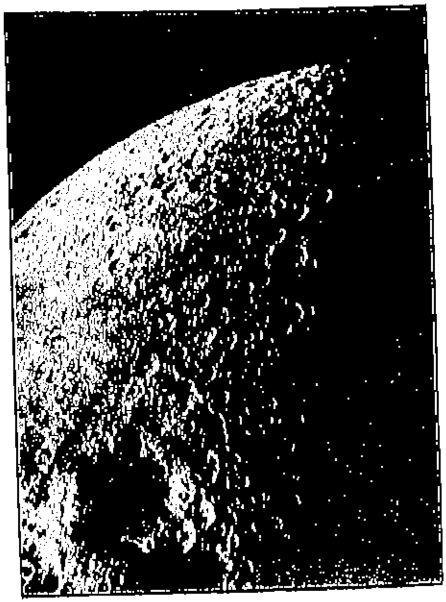


Fig. 35.—A portion of the moon. From a photograph taken by the Brothers Henry, at Paris Observatory.

tory was brought into requisition. The image of the moon produced by the great lens has a diameter of five inches. It is only necessary, then, to place a photographic plate so that this image falls upon its sensitive film in order to obtain direct pictures of our satellite. More beautiful photographs

than those obtained under these conditions can hardly be desired. Fig. 14 is a copy of one of the pictures. From an examination of the best pictures yet taken, Prof. Holden, the director of the observatory, concludes that parallel walls on the moon, whose tops are no more than two hundred yards or so in width, and which are not more than about one thousand yards apart, are plainly visible. Some photographs of the moon taken by Messrs. Paul and Prosper Henry of Paris, in the beginning of 1890, are even more remarkable than those produced by the astronomers of the Lick Observatory. The moon's image, instead of falling directly upon a photographic plate, was caused to traverse a second lens which magnified it fifteen times. The magnified image was then photographed in parts, though, of course, it would be possible to obtain a picture of all the parts at one exposure, if a very large photographic plate were employed. (Fig. 35.)

There is no doubt that enlarged photographs of our satellite are capable of affording more information regarding its surface than can be gained by years of diligent observation, while their multiplication at different epochs will enable astronomers readily to detect changes of a comparatively minute character in lunar formations.

Photography has revealed many of the secrets of solar constitution. With an instantaneous exposure, a sun-picture is obtained which records the exact positions and extent of all the spots and markings upon the sun's visible surface. Such photographs give definite knowledge of the fluctuations of spotted area from year to year; they are "above suspicion," and therefore provide the best means of accurately determining the speed of the sun's rotation, and of tracing the birth, life, and death of individual spots. And, greatest boon of all, these unbiassed records can be

referred to at any time. Dr. Janssen of the Meudon Observatory has brought the photography of the sun to a high state of perfection. With an instrument five inches in diameter he produces pictures showing as much of the fine detailed structure of the solar surface as is seen under the best conditions with the eye. The accompanying illustration is from one of the marvellous pictures taken by this observer. It shows a sun-spot broken into fragments

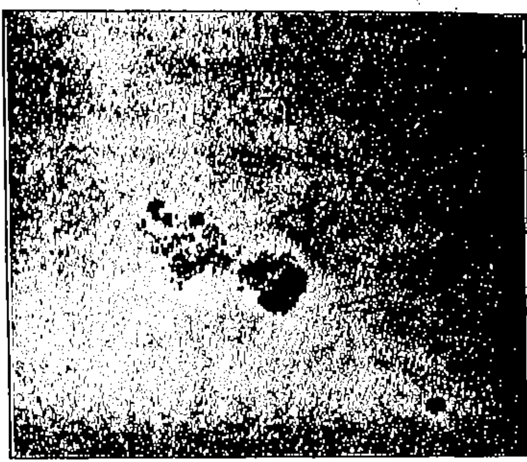


Fig. 36.—Group of sun-spots and the neighbouring solar surface. From a photograph taken by Dr. Janssen, at Meudon.

by terrible convulsions. Round the spots can be seen the converging filaments forming the penumbra, and shooting over the large spot is a bright bridge of a kind often observed. The solar surface is seen to have the granulated structure, to which reference has previously been made, and parts of it appear hazy. The latter appearance is not due

to any instrumental or photographic defect, but is found upon each of a series of pictures taken in succession, and therefore belongs to the sun. These hazy areas or smudges change in appearance and position much more rapidly than sun-spots, an interval of an hour being sufficient to show remarkable differences. Professor George E. Hale, of Chicago, has recently obtained marvellous results in solar photography. By a device which it is beyond our limits to describe, he obtains on a single picture all the prominences, sun-spots, and faculæ in existence at the time of exposure. The photographs show that sun-spots are only the visible portions of much more extended regions of disturbance.

Photography was first applied to the eclipsed sun in 1842. By means of pictures taken at successive stages during the eclipse of 1860, the prominences were proved to belong to the sun, and photographs of the corona taken at widely separated stations showed that this halo of silvery light is a solar appendage, and not a phenomenon produced by our own atmosphere. A significant fact with regard to the development of eclipse photography is that the work of both the English expeditions which set out to view the total eclipse of the sun on April 15, 1893, was to obtain photographs showing the structure and extent of the corona, and photographs of the coronal spectrum, visual observations being left out of count altogether.

A few fine photographs of planets have been taken by different astronomers. With the Lick Observatory telescope, pictures of Jupiter have been obtained showing many of the markings upon his disc, and Prof. Pickering has also done excellent work in this direction, but it can hardly be said that the pictures are anything like so perfect as those of the moon and sun.

Dr. David Gill, of the Cape Observatory, obtained several

splendid photographs of the Great Comet of 1882, and the accompanying illustration is a copy of one of them. It will be seen that the stars are all elongated in one direction. The amount of elongation represents the distance through which the comet moved during the time of exposure.

Fig. 37.—Photograph of the Great Comet of 1882, obtained at the Cape Observatory by Dr. Gill.

Comets, as we have before remarked, are celestial vagabonds. They have no fixed abode upon the vault of heaven, but wander from point to point. Dr. Gill wished to photograph the comet, so he followed it up with his telescope, keeping time with it instead of the stars. Photographs of other

comets have been taken, but there has been no opportunity of obtaining pictures of such a large object as that which appeared in 1882.

A photographic register of a comet would be invaluable for the computation of the orbit, and for an intelligent study of the marvellous changes which take place in the body's head and tail as it approaches and recedes from the sun.

The last two or three years have witnessed a new departure in celestial photography. The astronomers of the Lick Observatory, and Dr. Max Wolf, of Heidelberg, have photographed a number of beautiful pieces of celestial scenery by means of a lens, precisely similar to the lens of an ordinary camera, but larger, being about thirty inches long and five inches in diameter. Such lenses have the advantage of taking in a much wider expanse of sky than is possible with a telescope. Dr. Wolf has accumulated faint impressions upon his plates for so long as twenty-four hours by exposing the lens to the same portion of the sky on successive evenings. On one of these long-exposure photographs a luminous trail was observed, which proved to be the trail left by a meteor as it shot across the field of view while the sensitive plate was directed heavenwards. An examination of another photograph showed the existence of a short luminous line. This turned out to be a minor planet, whose movements among the stars during the time of exposure had caused it to be registered as a line instead of a point. A new method of discovering minor planets was thus opened up, and astronomers have not been slow to take advantage of it.

Attempt to draw a patch of mist lying over a water surface in the evening or a thin bank of fog, showing not only the extent of the haziness but the light and shade of its parts, and you will obtain an idea of the difficulty of ac-

curately delineating the masses of celestial haze known as nebulæ. From 1659, when Huyghens published the first drawing of the Great Nebula of Orion, to 1880, when Dr. Draper took the first photograph of it, one observer after another has attempted to reproduce its ghost-like structure,

Fig. 38.—The Great Nebula of Andromeda. From a photograph by Dr. Isaac Roberts.

and the results are often so different that it is difficult to believe that the same object is represented. Dr. Draper's results showed clearly that much was to be expected from photography as a nebula-artist, and a picture obtained by

Dr. Common, in 1883, proved the art worthy of the trust which was put in it. Details and extensions of the nebula, which had been unknown, were revealed by his photographs.

Dr. Isaac Roberts was the next worker in this field of inquiry. It was he who began to take the long-exposure photographs which mark an epoch in the history of celestial photography. A photograph of the Orion nebula taken with an exposure of four hours shows twice as much nebulosity as that exhibited in Dr. Common's pictures. Unaccountable dark lines or rifts which had been seen on the side of the Great Nebula of Andromeda are shown by Dr. Roberts' photograph of the object to be divisions between rings of luminous matter, extending completely round it, like the rings round the planet Saturn.

In 1885, the Henry Brothers obtained fine photographs showing nebulous material round some of the Pleiades cluster of stars. A year later, Dr. Roberts, by means of a photograph taken with an exposure of four hours, showed that the whole of the stars in the cluster are immersed in nebulosity, whereas not a trace of this cloudiness can be seen with an ordinary telescope. It would take up too much space to enumerate the valuable results which this astronomer has obtained. Clusters of stars of all description, and nebulæ of every kind have been forced to register their forms upon his photographic plates. He has done much; still more can be confidently expected.

Nearly a quarter of a century ago, Dr. Rutherford pointed out that photography could be applied to the mapping of the stars. The idea lay dormant until Dr. Gill's photograph of the comet of 1882, showing numerous stars down to the ninth magnitude, and some remarkable photographs taken two years later by M. Henry, and showing stars down

to the sixteenth magnitude, revived it. The success clearly indicated that nothing was wanting but the co-operation of astronomers all over the world to construct a photographic map of the whole sky. A congress composed of fifty-eight members, and representing sixteen different nationalities, was therefore convened at Paris in 1887. It was then decided to prepare a photographic chart of the heavens, the stars to

Fig. 39.—"Dr. Roberts, by means of a photograph, has shown that the whole of the stars in the Pleiades cluster are immersed in nebulosity."

be photographed down to the fourteenth magnitude. Each separate picture will contain the stars in an area of four square degrees, and each star will appear upon two pictures, in order that any spurious spots accidentally produced by specks of dust can be discriminated. Before the map is completed, about twenty-two thousand plates will have to be exposed, each for about an hour, to the sky. Previous to

turning a plate to starlight, it is exposed to rays transmitted by a glass screen upon which a reticulation or network of lines is drawn. Faint lines are thus impressed upon the plate, the distance from one line to the next being one-fifth of an inch. After a plate has been marked in this manner, it is exposed to the stars and then developed. The stellar images thus appear together with the network upon the resulting pictures; so the positions of stars with respect to the intersecting lines can be very accurately determined. It is estimated that about twenty millions of stars will appear upon the plates exposed, so as to take in all those down to the fourteenth magnitude. Another set of plates have to be exposed for a shorter time so as to include stars to the eleventh magnitude only, the number in this case being one and a half millions. These plates are intended for the formation of a catalogue containing all the stars down to the eleventh magnitude. They have not merely to be exposed to the sky and developed, but each stellar point which appears upon them has to have its exact position afterwards determined. Though the work is well advanced, it can hardly be completed before the end of this century. It will be a fitting termination of a century so rich in astronomical discoveries.

If nebulæ are considered to be the starting-point in the life-history of worlds, their growth can be traced in the manner referred to in the preceding chapter. When we go into a forest and see the brave old oaks which have stood in their might and majesty for hundreds of years, side by side with the saplings and the plants just sprouting from acorns, we know at once that the different forms represent different stages of development. Reasoning in this manner, Herschel concluded that the various forms of celestial bodies are the result of different ages, and that every world has been

fashioned out of the misty material we call nebulæ. Photography has been able to afford some information upon this matter. The nebula in Orion appears to represent the condition of things when "the earth was without form and void; and darkness was upon the face of the deep." Dr. Roberts' photograph shows that in the nebula of Andromeda we have a more symmetrical arrangement of matter. Round the bright nucleus are swirls of luminosity, which appear elliptical in form on account of their being inclined to the line in which we see them. The two small nebulæ near this "tumultuous cloud" have very probably been formed from it; they are worlds being called out of a void. A nebula such as that of Andromeda is therefore older than an irregular mass like that of Orion. The next stage of development is into a star cluster immersed in faint nebulosity, and then into clusters quite free from this "shining mist." Thus, by the aid of photography, we seem to be in the way to an intelligent classification of celestial species. In the broad expanse of heaven, we have:—

> "Regions of lucid matter, taking form:
> Brushes of fire, hazy gleams,
> Clusters and beds of worlds, and bee-like swarms
> Of suns, and starry streams."

Kant and Swedenborg speculated upon the evolution of the members of our system, and Laplace developed the matter mathematically. These philosophers showed that, in all probability, the space included within the limits of the solar system was, at one time, filled with a whirling luminous mass, similar in constitution to a nebula. This rotating ball of vapour gradually diminished in temperature, and, as it contracted by cooling, the rotation increased in rapidity until the centrifugal form became greater than the central

attraction, and rings or zones of nebulosity were left behind. The condensation of these rings produced planetary masses, which, by going through similar stages to the parent mass, gave birth to satellites.

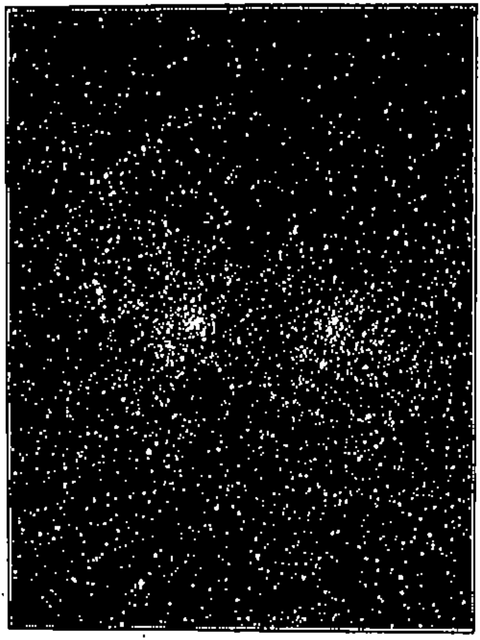


Fig. 40.—"Clusters and beds of worlds and bee-like swarms of suns." From a photograph taken by Dr. Isaac Roberts.

The planet Saturn is surrounded by rings, which will probably break up into satellites in this manner. According to this theory, Neptune is the first born member of our family, and Mercury is the youngest child of the sun. Lockyer's meteoritic hypothesis does not combat this theory,

for it has been shown that a condensing swarm of meteorites would behave like the condensing mass of gas upon which Laplace built his theory. There is also another way of looking at the matter. The nebular hypothesis begins with a ready-made gaseous nebula. Lockyer begins at an anterior stage by asserting that the mass of gas is the outcome of colliding solid particles. We have seen that the view of the conversion of nebulæ into stars and planets can be extended to the innumerable worlds distributed through the realms of space, though it can hardly be said that our knowledge of celestial evolution is of the most accurate character. By patient searchings man will obtain a deeper knowledge of the mystery of creation, and the light of science shall reveal much that is at present hidden. Let us conclude with a quotation from Lytton: "Upon a stratum, not of this world, stood the world-born shapes of the sons of Science, upon an embryo world—upon a crude, wan, attenuated mass of matter, one of the nebulæ which the suns of the myriad systems throw off as they roll round the Creator's throne, to become themselves new worlds of symmetry and glory—planets and suns that for ever and for ever shall in their turn multiply their shining race, and be the fathers of suns and planets yet to come."

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